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# ELECTRIC LIGHTING BY INCANDESCENCE.

SAWYER.

# ELECTRIC LIGHTING

BY

# INCANDESCENCE,

AND ITS

# APPLICATION TO INTERIOR ILLUMINATION.

---

*A PRACTICAL TREATISE.*

---

WITH 96 ILLUSTRATIONS.

BY

WILLIAM EDWARD SAWYER.

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# PREFACE.

THE subject of electric lighting by incandescence is one of general interest. Its brilliant promises have excited the curiosity and the anticipations of the public to a degree almost unprecedented in the history of invention. But beyond the threshold of the laboratory its processes are unknown, and information which would be of service to experimentalists is withheld.

My purpose in preparing this work is not alone to show the state of the art in its practical applications, but also to indicate the direction in which the laborer in science is most likely to attain success, and to impart an accurate conception of the principles underlying the employment of electricity for interior illumination.

Special description of lighting by the voltaic arc is omitted, for the reason that the subject is fully discussed in numerous text-books readily obtainable, and because there are few cities in which this form of lighting may not now be seen in operation; while to the subject of electric generators, which constitute the beginning and the end of any system of lighting, considerable space is given.

Those who expect to find these pages the vehicle of a theory will be disappointed. Those who expect to find them devoted to criticism of the labors of other experimentalists will be equally disappointed.

In the position of an impartial student and observer I have sought less to indicate defects than to exhibit accomplishments.

WILLIAM EDWARD SAWYER.

NEW YORK, January 15, 1881.

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# INTRODUCTION.

WHEN the free ends of two conducting wires connected with the terminals of a galvanic battery, or other generator of electricity, are brought together, the circuit of the generator is completed, and a current of electricity more or less powerful, according to its quantity and electro-motive force, traverses the elements of the generator and the conductor uniting its terminals. This conductor offers a certain resistance to the passage of the current which may generally be disregarded. The generator offers a considerable resistance, and the current appears as heat in its elements, for the reason that the current is divided between the generator and the conductor in proportion to their respective resistances; and the calorific effects of current in any conductor are proportional to its value in that conductor. If, now, we separate the ends of the conducting wires, the movement of separation involves primarily a poor connection at the points of contact, and a poor connection means resistance; hence the former relations of the generator and the conductor are disturbed, and the current being distributed exactly in proportion to the resistance of any part of the circuit, a less proportion is found in the generator and the remainder is concentrated at the imperfect points of contact, where it produces heat sufficient to fuse and then to vaporize them; and as the vapor of a conductor is also a conductor of electricity, the current traverses the break between the points of contact, as they are drawn apart, to a distance commensurate with the intensity or electro-motive force of the current. The vaporized conductor uniting the points of contact constitutes the voltaic arc, the most brilliant and dazzling of all artificial lights. In the Serrin, Siemens, Jablochkoff, Brush, and other lamps, the arc is formed between the ends of carbon rods or pencils; and the light is more intense and economical when the distance between the carbons is slight and the current great in quantity than when the reverse is the case.

The voltaic arc is the most economical of electric lights; and in the illumination of large open spaces, and for all purposes requiring much penetrative power, it will doubtless maintain its supremacy. In many cases of experimental test it has developed a light of from 1,000 to 2,000 candles per horse-power of force expended in driving the generator, the cost of which in large steam-engines is less than one cent per hour.

In both the voltaic arc and the incandescent forms of lighting the dynamo, or the magneto-electric, type of generator is now universally employed. Each type of machine is designed to transform mechanical force into electricity. The magneto-electric machine is that in which the magnetic field is derived from a permanent magnet. The dynamo-electric machine is that in which the permanent is replaced by an electro-magnet. Both operate upon the same principle—that the cutting of a line of magnetic force by an endless conductor of electricity, constituting a closed circuit, induces in the latter a current whose direction is determined by the direction of motion of the conductor, or the direction of polarity of the magnetic field. The machines of Pixii, Clarke, Nollet and Van Malderen, Ladd, Wilde, and others are examples of both magneto and dynamo-electric generators, but they have all succumbed to the superior apparatus of the present day. Of these old machines we shall consider the generator of Wilde as embodying a principle which is destined to play an important part in the utilization of electricity for the purposes of domestic illumination.

# ELECTRIC LIGHTING BY INCANDESCENCE.

## CHAPTER I.

### GENERATORS OF ELECTRICITY.

THE value of a pound of coal in mechanical energy is about 12,000,000 foot-pounds; the value of a pound of zinc is about 1,845,000 foot-pounds. The cost of a pound of zinc is about twenty-five times the cost of a pound of coal. With this great discrepancy between the energy and cost of the one and the energy and cost of the other, and after making due allowance for all the facts favorable to zinc, it is clear that in electric lighting, at least, the period of usefulness of the galvanic battery has passed, not to return. The discovery by Faraday, in 1831, of magneto-electric induction, and the construction by Pixii, a year later, of the first magneto-electric machine, mark the beginning of the era of conversion of mechanical power into electricity; but we shall not attempt to describe the efforts of the earlier experimenters, who, although far in advance of their times, made little progress toward the realizations of the present day. After Pixii came Saxton, in 1833; Clarke, in 1836; Nollet and Van Malderen, in 1849; and Holmes, in 1852, all of whom employed the magneto-electric principle. In

1857 the Siemens armature was invented, and subsequently, in 1866, Wilde constructed his remarkable machine (Fig. 1).

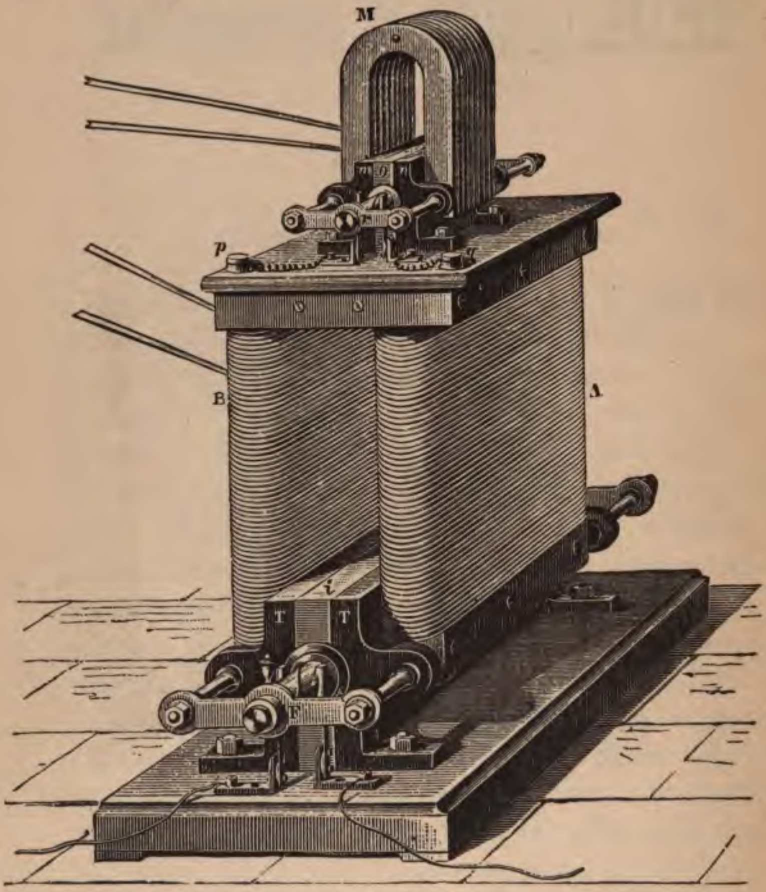


Fig. 1. The Wilde Machine.

The Wilde machine consists of a Siemens armature whose electro-magnetic field of force is sustained by an exciting machine of the magneto-electric typè. It is, therefore, a double machine, each part of which is provided with a Siemens armature, whose advantages are that it occupies but little space, and may therefore be rotated in a magnetic field of maximum intensity; and whose disadvantages are the high speed of rotation necessary, and excessive heating by reason of the rapid changes in its molecular structure consequent upon the rapidity of its rotation while cutting the lines of magnetic force. Between the opposite poles of a compound permanent horseshoe magnet the armature is placed, and its rotation is effected by means of a belt passing over the pulley shown in Fig. 2. The Siemens armature has not gone out of use, for its simplicity and cheapness of construction continue to commend it. In electro-plating and laboratory work it finds constant employment.

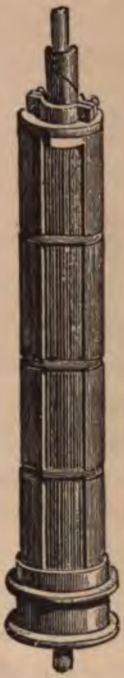


Fig. 2. Siemens Armature.

Primarily, the Siemens armature consists of a roller of wrought or cast iron in which deep, longitudinal grooves are cut, whereby its section is reduced to a form similar to that of the letter H. Lengthwise in these grooves the induction helix of insulated wire is wound. In Fig. 3 we have a section of the armature and the field magnet polar extensions of the lower machine.

In the upper or magneto-electric machine, the inductive action is derived from the permanent magnets M, whose extremities are in contact with the soft-iron polar extensions, *m n*, forming the sides of a socket within which the armature rotates. The current generated in the armature-coil flows from the commutator to the binding-screws *p q*, which are the terminals of the large electro-magnet coils, A B, through which the current circulates. The lower extremities of the large magnet are in contact with two iron polar extensions, T T, separated by a mass of diamagnetic metal, *i*; and the second Siemens armature, of large size, furnishes the current for external use. F is the bearing of the armature-shaft. A B, M N (Fig. 3) represent the socket within which the armature revolves, the portions A B being of iron and M N of brass or other diamagnetic material. By employing the current induced in the armature of the superposed magneto-machine to excite the electro-magnet of the lower dynamo-machine, there is established in the lower machine a much more powerful magnetic field than that of the compound permanent magnet of the upper machine, and from the lower armature a current of much greater power than that induced in the upper armature is obtained. The polarity of the armature is reversed at each half-revolution, and the alternately opposite

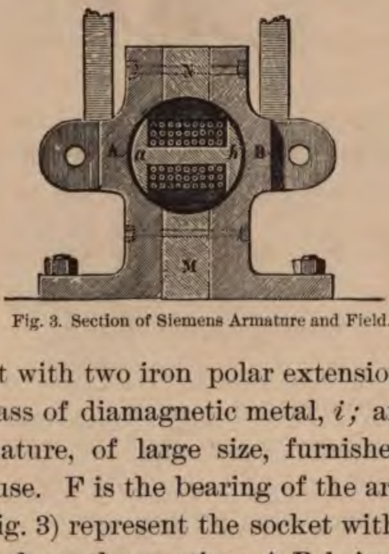


Fig. 3. Section of Siemens Armature and Field.

currents are reduced to a common direction by means of a commutator (Fig. 4).

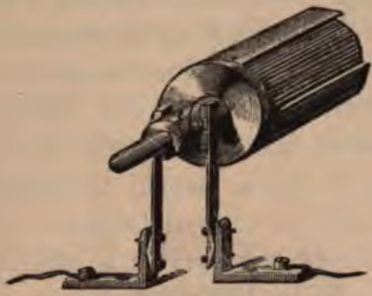


Fig. 4. Commutator.

The calorific effects of the Wilde machine, whose principle may be extended indefinitely, are most remarkable; but it should be borne in mind that in no machine can the electrical energy evolved exceed the mechanical force expended in producing it.

In the Wilde machine we have the germ of a perfect generator. The field of force of the lower armature is created and sustained by an invariable exciting current. Its intensity, therefore, does not depend upon the resistance of the external working circuit. The resistance of the armature-coils may be a tenth or less of the resistance external thereto, so that ninety per cent. or more of the current generated in the machine may be utilized in the production of light.

Opposed to the principle of Wilde is that of accumulation by mutual action, in which the currents induced in the armature are made to circulate through the coils of the electro-magnet that induced them. The magnetism residual in the iron of the electro-magnet induces at first a weak current in the armature-coils, and this, being returned to the magnet-coils, increases the power of the magnet, and induces in the armature a correspondingly powerful current, which is again returned to the magnet-coils; and this action progresses until a point of magnetic saturation is attained. The principle of accumulation by mutual action is employed in the Häfner-Alteneck, the Gramme, Brush, Hochhausen, and other generators in general use; and where a single lamp, or a limited number of lamps, is to be operated, it does not appear advisable to employ an exciting machine, the practical use of the latter being in the lighting of buildings or sections of a city requiring a large number of lamps and a common source of supply.

In all accumulative machines increase of resistance in, or interruption of, the external circuit at once cuts down or destroys the field of force, for the field of force is dependent entirely upon the resistance of the circuit, and we have the most effective work when the resistance external to the machine is sensibly equal to its internal resistance, although it is often possible to obtain satisfactory results when the external is greatly in excess of the internal resistance. As the field of force must be created by the charging-up of the magnet upon its own circuit, it is clear that when we increase the external resistance the field of force is weakened, and very soon a point is reached at which the magnet will not appreciably charge. Thus it is that a dynamo-machine may successfully operate a single lamp, or a limited number of lamps, while it will produce no good effect when two or a greater number of lamps are connected in circuit, and in order to obtain the best results—*i.e.*, the maximum of light with the minimum expenditure of power—substantially fifty per cent. of the current generated is ordinarily expended in exciting the machine, and fifty per cent. in the production of light. Compensating for increased resistance in the external circuit by increasing the speed of the generator above its normal velocity is wasteful of power.

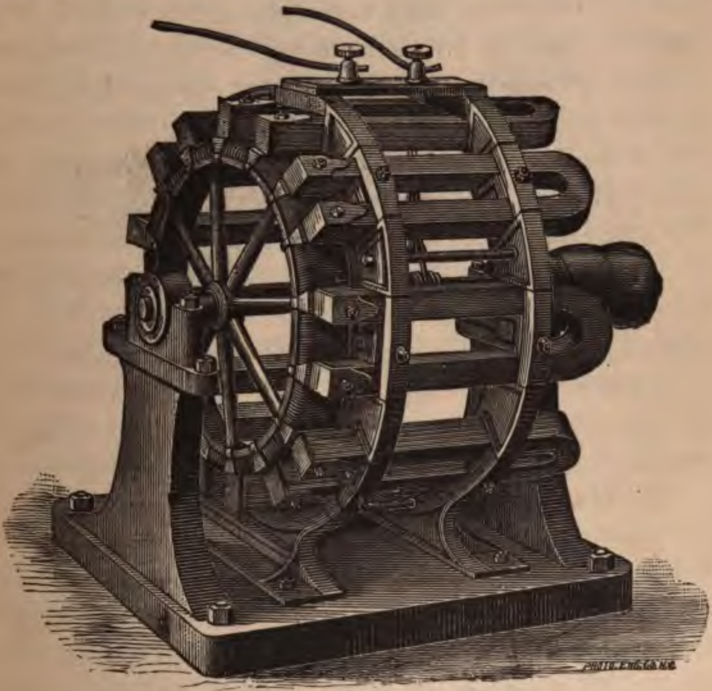


Fig. 5. The De Meritens Machine.

The permanent field magnet of the earlier machines has generally given way to the more compact and powerful electro-magnet, but in the recent invention of De

Meritens (Fig. 5) the original form of magnet is revived. For this machine great efficiency has been claimed; and that within certain limits it is an economical generator of electricity we have no reason to doubt. The saving of the power expended to sustain the field of force of dynamo-electric machines is, of course, advantageous; but the cost of construction, multiplication of parts, and cumbersomeness of large generators designed upon this plan will probably operate against them, as they have operated against the similarly-designed Alliance and Holmes machines. In construction the De Meritens machine consists of a series of grooved armatures, like the letter H, joined side by side and mounted upon the periphery of a diamagnetic wheel, so as to constitute an iron ring in sections, provided with as many projections as there are distinct pieces. In the bottom of the grooves the armature coils are wound; and the whole is rotated within the fields of force of a series of powerful steel magnets, built up of thin plates and supported in a circular frame. The methods of adjustment of parts employed by De Meritens are simple and effective.

The Lontin distributor (Fig. 6) is one of several new forms of generators, embodying the principle of Wilde, designed to operate a considerable number of lamps from a single source. The exciting machine is of the dynamo-electric type, and consists of an electro-magnet between the poles of which revolve a number of radially-arranged bar electro-magnets constituting the armatures. The current produced is employed in sustaining the fields of force of the distributor, which consists of a large, stationary, soft-iron ring, F, to which are secured equidistantly a series of short electro-magnets, B, equal in number to the electro-magnets, M, of the inner revolving wheel. The revolving magnets, which are connected in multiple circuit, are charged by the exciting machine and constitute the fields of force. As the ends of the revolving magnets present alternately opposite poles to the poles of the stationary magnets, alternating currents are induced in the latter, and as many separate lamps may be worked from a single distributor as there are electro-magnets B.

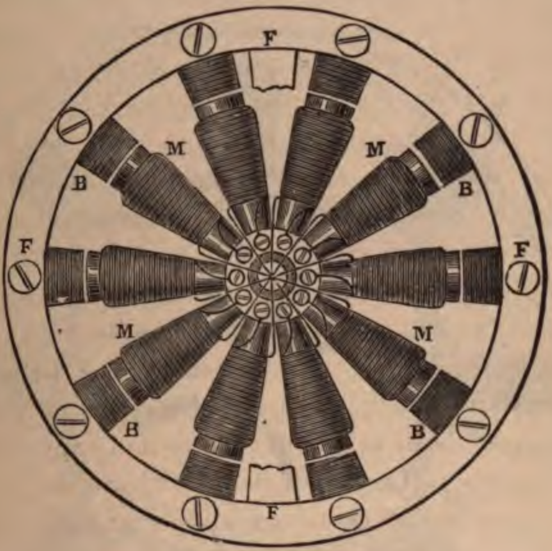


Fig. 6. Lontin's Machine.

Regarding the performance of the Lontin distributor, it is stated that in the small machine the light obtained per horse-power of mechanical force expended is from 400 to 600 candles, while in a larger machine, having a capacity of 12 lights, and consuming twelve horse-power, the light obtained per horse-power is from 600 to 750 candles. A generator used at the railway station at Lyons fed 31 separate lamps, each having an illuminating power of 340 candles, but the value of the mechanical energy expended is not known.

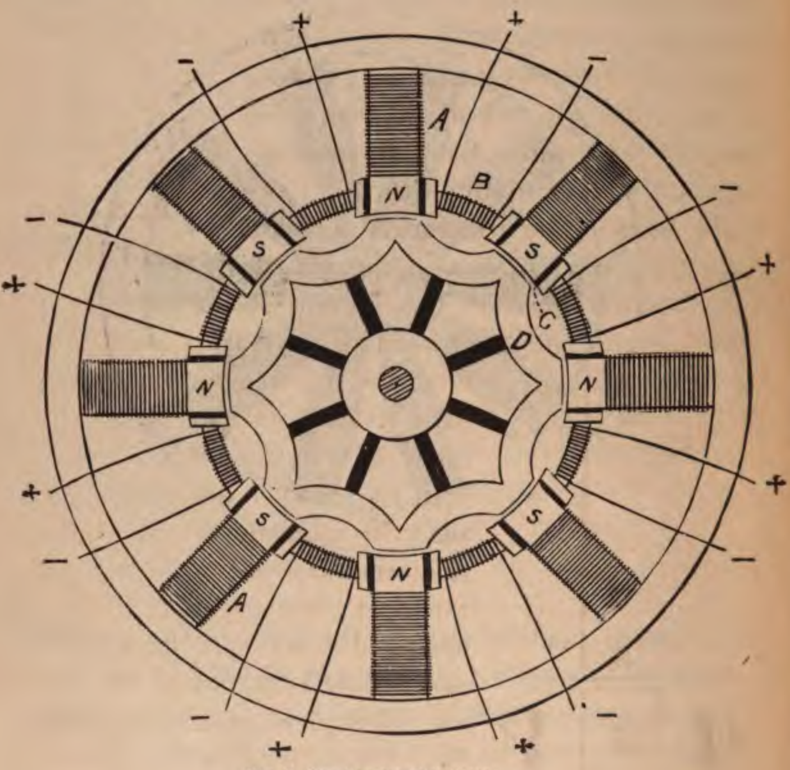


Fig. 7. The Sawyer Distributor.

The Sawyer distributor (Fig. 7) bears a certain resemblance to the Lontin machine, but is based upon a different principle of action.

It is a well-known fact that for every magnet there is a point of maximum sustaining power. Taxed beyond that point, the magnet will no longer sustain its armature. Suppose that we have a magnet, N S (Fig. 8), whose armature or armatures, A, require all its power to sustain them. If, now, we bring to the magnet a third armature, B (Fig. 9), greater in mass than either of the armatures A, both armatures A will fall off, because armature B, of greater mass, operates to magnetically short-circuit them. If we have, surrounding armature A, a coil of insulated wire, when we approach the magnet with armature B a current of electricity is induced in that coil; and when we move armature B away, armature A being within the magnetic field, a current of opposite direction is induced in the coil.

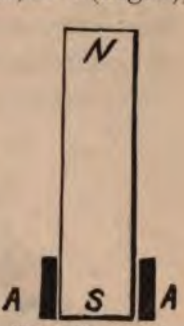


Fig. 8. Magnet and Armatures.

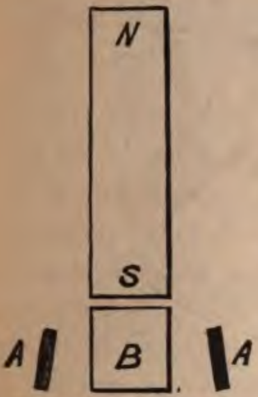


Fig. 9. Magnet with unequal Armatures.

In the Sawyer distributor both the field magnets and their induction armatures are stationary. To the inner periphery of an iron ring are fixed a series of electro-magnets whose coils, joined together, are fed by an exciting machine. Bolted to the sides of the polar extensions of the magnets by means of brass screws, and prevented from magnetic contact by brass plates, C, are the soft-iron armatures B, whose coils are connected with the lamps to be operated. A soft-iron armature, D, designed to short-circuit the magnetic force of the field magnets, is rapidly rotated, its projections approaching almost to contact with the polar faces of the field magnets. The cross-section of D is much in excess of the cross-section of B; consequently, when the former is in the position shown, the magnetic force is almost entirely short-circuited from B. As the position of the projections of D is changed, the magnetic force of the field magnet is directed through the armatures B, and a current of electricity of one direction is induced in their coils; as the projections assume the position shown a current of the opposite direction is induced. By means of this generator a large volume of electricity is obtainable, but in effective action it seems to be inferior to some other generators.

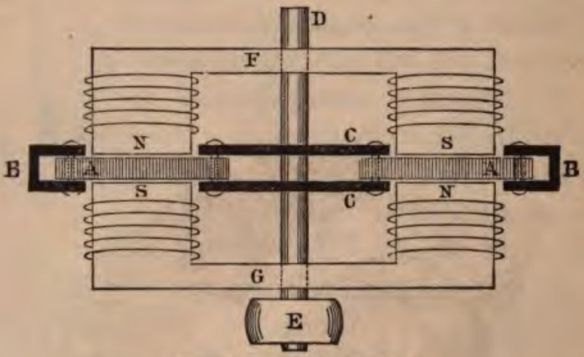


Fig. 10. The Seeley Machine.

The Seeley machine (Fig. 10), which appeared in the year 1880, contemplates an armature entirely of copper wire or ribbon (the iron core being discarded), in order that loss of power consequent upon its conversion into heat, and the injurious effects of Foucault currents, may be avoided. F and G are electro-magnets arranged with the N pole of one magnet opposite to the S pole of the other. The space between each opposite pair of poles is from one-fourth of an inch to an inch, and in this narrow space, constituting a concentrated and intense magnetic field, the radial wire armatures A are rotated. The method of winding the armatures, which are held in place by a central clamping device, C C, fixed to shaft D, and an outer clamping-ring, B, is shown in Fig. 11.

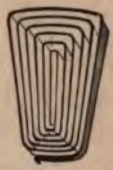


Fig. 11. Armature of Seeley Machine.

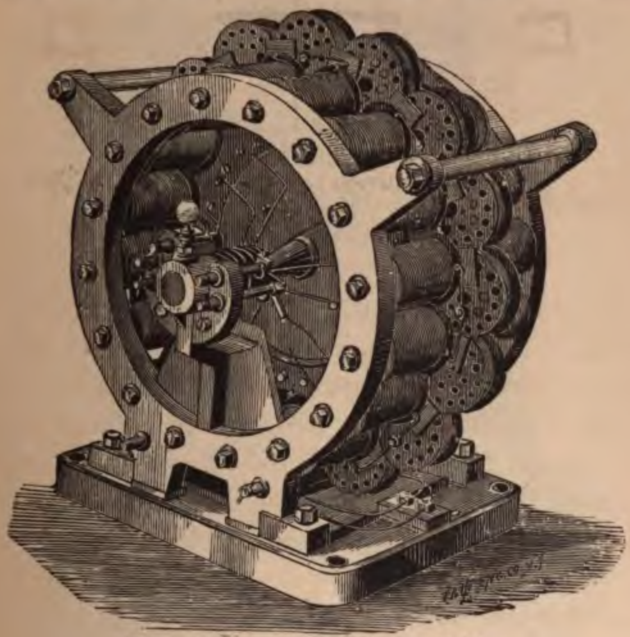


Fig. 12. Siemens Alternating Current Machine.

The shaft of the machine is rotated by means of pulley E. In practice there are six magnets on each side of the armature-disk, and twelve armatures.

A form of alternating-current machine, the same in principle as the Seeley machine, was devised by Siemens and Halske in 1878, and consists in one form of a central disk carrying coreless wire helices (Fig. 12). This disk is rapidly rotated between two sets of electromagnets whose fields of force are sustained by a small Siemens continuous-current machine.

# CHAPTER II.

## GENERATORS OF THE GRAMME TYPE.

OF dynamo-electric generators none are better known, or more extensively employed, than those of M. Gramme, whose invention has excited the interest of the scientific world since its first presentation to the

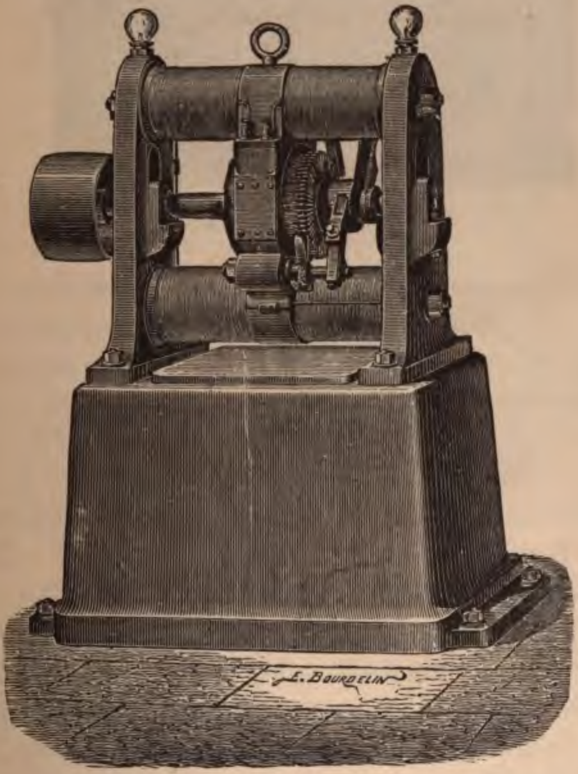


Fig. 13. The Gramme Machine.

French Academy of Sciences in 1871. The essential feature of the Gramme machine (Fig. 13) is a soft-iron ring wound throughout, in the same direction, with a continuous insulated copper wire, the terminals of which are joined together, so that the whole constitutes an endless wire helix (Fig. 14).

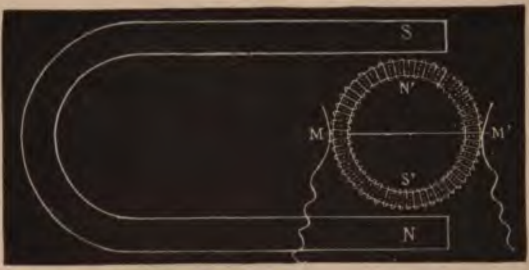


Fig. 14. Principle of the Gramme Machine.

In order to arrive at an understanding of its operation, let us suppose that the wire is denuded upon the periphery of the helix, thus forming a band, composed of bared sections of the wire, running around the outer circumference of the ring. In this we have one element of the commutator, the other of which is composed of the collecting brushes, M M′, which make connection with the bared sections of the helix. When the ring is placed between the poles, S N, of any magnet, the ring constitutes the armature of that magnet, and there occur in the ring two consequent poles, S′ N′. If the ring is now revolved the poles developed in the ring remain invariably in the same relation with respect to the magnet poles, N S. Whatever may be the rapidity of rotation, the ring poles, N′ S′, remain fixed in space and each part of the copper helix successively traverses them. It is apparent, therefore, that the helix will be the seat of a current of one direction when traversing the path M S M′, and of the inverse direction when traversing the path M′ N M; and the part of the helix above the line M M′ will be traversed by a current of one direction, and all parts beneath the line by a current of inverse direction, precisely as in the case of two galvanic batteries, each composed of an equal number of elements, coupled in multiple or opposition. The two currents are equal and opposite and balance one another.

Generally the ring is made of iron wire (Fig. 15), and in practice the helix is not denuded for the purpose of establishing current-collecting faces, but is divided into short coils so connected as to constitute an endless coil wound in one direction around the ring, the connecting wires between the coils being connected with substantial insulated pieces nearer the shaft, which, together with the collecting brushes, compose the commutator. In the Gramme machine there are no sudden reversals of polarity in the ring, but a continuous progressive movement of the consequent poles, which are subject to displacement in respect of the poles of the magnet in proportion to the velocity of rotation of the ring.

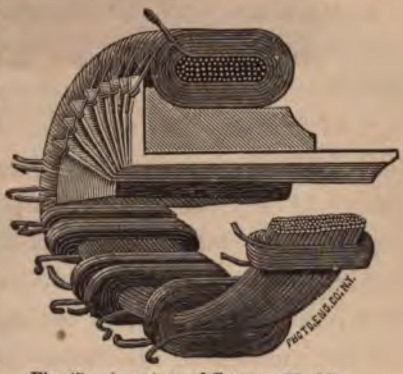


Fig. 15. Armature of Gramme Machine.

To produce a successful Gramme machine, it is necessary to provide the magnet with polar extensions overlapping from two-thirds to five-sixths of the outer periphery of the ring, and the distance between the iron of the ring and the faces of the polar extensions presented to its outer periphery should in no case exceed one and a half inches, and in small machines should not exceed one-half inch. The helix must be wound so as to bring the layers of wire within this space, and the polar faces should be in as close proximity to the outer periphery of the helix as may be compatible with safety in mechanical construction.

In the Gramme, as in all other machines provided with iron induction-cores, the heating of the armature-coils is often a serious defect, especially when the velocity of rotation is great and the resistance of the external circuit low: and in some machines the heat developed is so great as frequently to be destructive of the insulations. Many attempts to obviate excessive heating have been made, attended with a greater or less degree of success, the most common of which is by increasing the number of armatures in respect of the number of magnets, as in multisectional machines. Another method is to run a stream of water through the shaft of the armature; or, as in the Hochhausen electro-plating machine, to run the entire armature in a water-box, the armature-helix being carefully insulated; or, as in the Sawyer machine, to cause the water to flow throughout the interior mass of the iron. A third method is to so construct the armature as to subject it to the free circulation of currents of air.

In the Maxim machine (Fig. 16), the last-described method is employed. This generator, which has recently been introduced and successfully operated in New York and other cities, is based upon the Gramme principle as to its armature, with some changes in

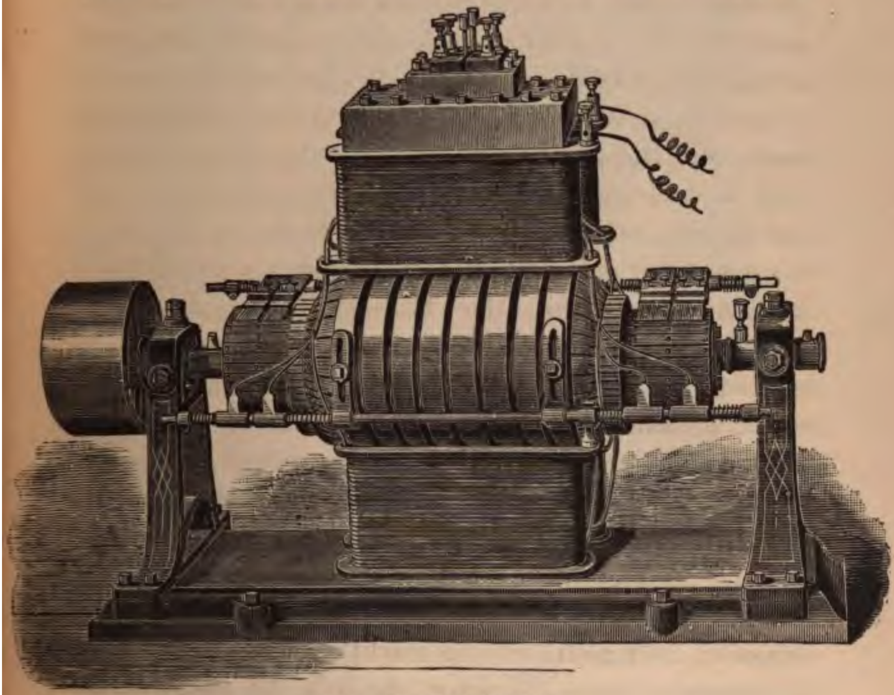


Fig. 16. The Maxim Machine.

the construction of the ring, which is composed of a large number of thin flanges of soft iron arranged side by side so as to form a tube or hollow cylinder of considerable length, through all parts of which the air is free to circulate. The electro-magnet is similar in construction to the compound magnet of Dr.

Siemens. No comparisons of the efficiency of the Maxim machine with other generators have been made; but unless the resistance of the external circuit is low, the armature is not heated so highly that the hand may not be placed upon it.

In some respects similar to the Gramme is the Brush machine (Fig. 17), whose extensive employment throughout the United States has demonstrated its efficiency in the production of a series of voltaic arcs. The Brush armature consists of a flat ring of soft cast-iron revolving in its own plane. This ring is composed of two or more parts, insulated from each other, and each provided with a series of grooves designed to prevent the induction of currents in the iron of the ring itself, and to confine the action of the field of force to the generation of currents in the eight helices with which the ring is wound. The stationary electro-magnets face both sides of the armature in the plane of its rotation, the faces of the magnets opposite to each other being of the same polarity; hence the soft-iron ring consists, as in the Gramme machine, of a compound semicircular magnet whose poles, fixed in space, are constantly changing in respect of the mass of the ring. In the arrangement of the armature-helices, however, the Brush machine differs essentially from the Gramme. They are not connected together to form a continuous circuit, but each pair of diametrically opposite helices is connected with diametrically opposite segments of the commutator, which segments are not connected with any other helices. Thus each pair of helices is entirely independent of the others. The object of this arrangement is to remove

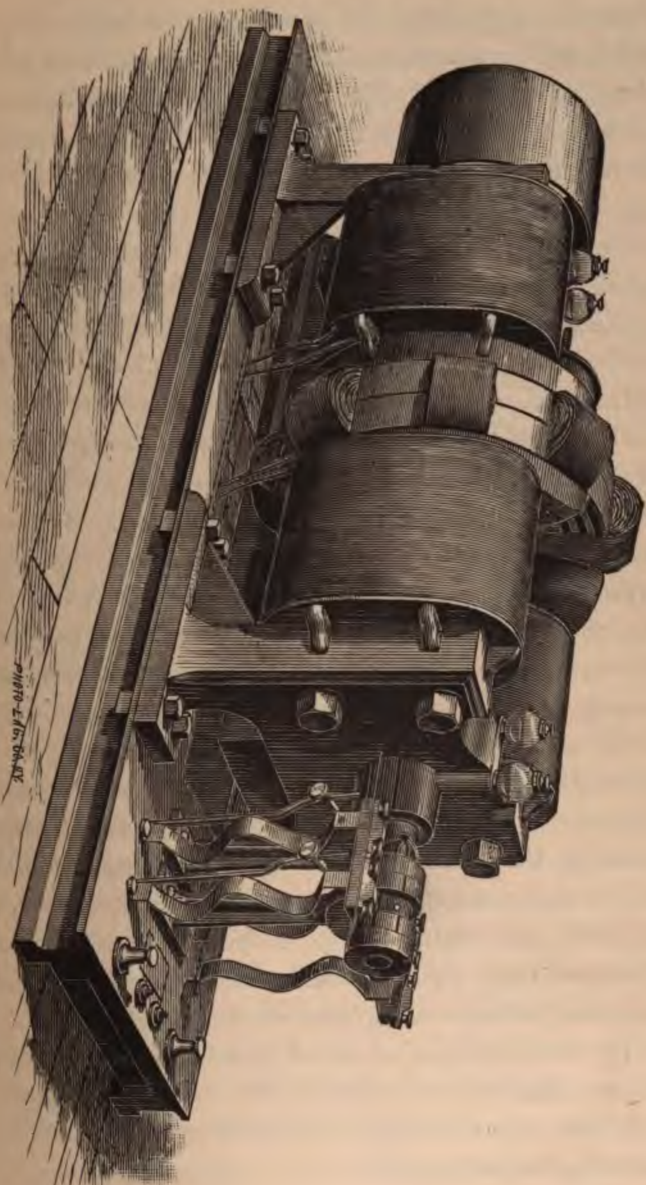


PHOTO-ENG. CO. N.Y.

Fig. 17. The Brush Machine.

from the circuit of the machine that pair of helices which, at the neutral point, not only contributes nothing in useful effect, but adds to the internal resistance of the machine. Thus in the Brush machine three-fourths of the armature-helices only are included in the circuit at any one time.

Various sizes of the Brush generator are manufactured, the sixteen-light machine being employed to a considerable extent in the lighting of streets, wharves, hotels, and factories. The resistance of the useful armature-coils is from four to six ohms, and the resistance of the magnet-coils from six to eight ohms, making the total internal resistance of a sixteen-light machine from ten to fourteen ohms. The resistance of the external circuit is the sum of the resistance of all the lamps, the internal resistance of each of which varies from one to five ohms. It is stated by the manufacturers that the sixteen-light machine (the diameter of whose armature is twenty inches, and length of base sixty-eight inches), driven at a speed of 750 revolutions per minute, absorbs about one horse-power per lamp. In his statement of the efficiency of his system, Mr. Brush says that as many as 33 lamps have been operated simultaneously in the circuit of this machine at a speed of 800 revolutions, with an arc of appreciable length in each lamp; but the total light produced was less than half that obtained when sixteen or seventeen lamps were employed.

The investigations of the Franklin Institute as to the relative efficiency of the Gramme and Brush machines (1877–78), in maintaining the voltaic arc, resulted in the following determinations :

"The Gramme machine is the most economical, considered as a means for converting motive power into electrical current, giving in the arc a useful result equal to 38 per cent., or to 41 per cent. after deducting friction and the resistance of the air. In this machine the loss of power in friction and local action is the least. The large Brush machine comes next in order of efficiency, giving in the arc a useful effect equal to 31 per cent. of the total power used, or 37½ per cent. after deducting friction."

As the result of the Franklin Institute experiments it was shown that the Brush machine, at a speed of 1,340 revolutions per minute and consuming 3.26 horse-power, developed a light of 1,230 standard candles, or 377 candles per horse-power; while the Gramme machine, run at a speed of 800 revolutions and consuming 1.84 horse-power, produced a light of 705 candles, or 383 candles per horse-power. In running 25 minutes the Brush machine increased in temperature from 73½° to 88° Fahr. The internal resistance of the machine was .483 of an ohm, and the resistance of the lamp .54 of an ohm. The internal resistance of the Gramme machine was 1.669 ohms, and the resistance of the arc 1.87 ohms.

Underlying the principle of the Gramme generator, but coming to general notice subsequent to the invention of Gramme, is the Pacinotti ring machine, devised by Dr. Antonio Pacinotti in 1860, and described in the June number of the Italian scientific journal, *Il Nuovo Cimento*, four years later. The Pacinotti machine (Fig. 18) was the first machine to produce a current of electricity continuous in character and constant in direction and intensity; and it differs from the Gramme in principle solely in that the revolving ring is provided with projections, as in the Brush machine, between which the endless helix is wound. Although the design of Pacinotti was to produce an electro-magnetic engine, he clearly described its conversion into a generator capable of producing, in combination with a permanent or an electro magnet, a continuous current of constant direction. The chief improvement of Gramme consisted in omitting the projections upon the ring, and covering the entire mass of iron with the wire helix; but the percentage of gain from this change in construction is not known. In general construction, however, the Gramme generator is new, and superior to the Pacinotti ring machine.

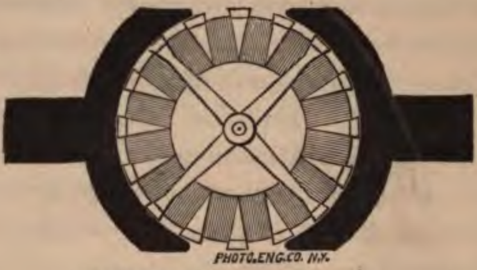


Fig. 18. The Pacinotti Ring Machine.

## CHAPTER III.

### GENERATORS OF THE NEW SIEMENS TYPE.

FOLLOWING the generator of M. Gramme comes the equally remarkable invention of v. Häfner-Alteneck (Fig. 19), generally known as the New Siemens machine, the compound electro-magnet of which has the flat shape

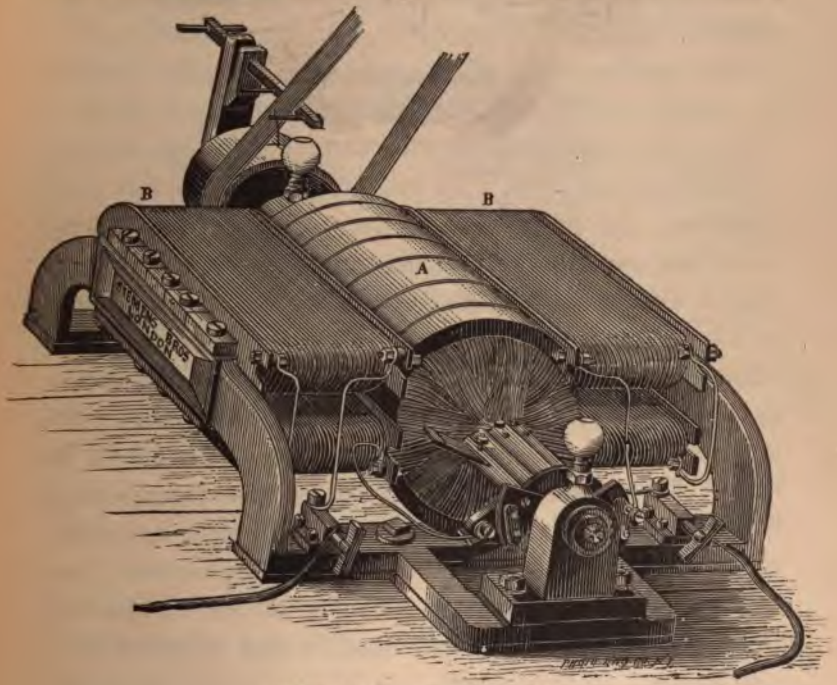


Fig. 19. The New Siemens Machine.

of the magnet of the Wilde machine. In this generator the armature consists of a long, soft-iron, hollow drum rotating between the curved polar faces A of the electro-magnet B. This drum is wound longitudinally, and in a peculiar manner, with insulated wire, covering all parts of the same, and connected, at different points, with the insulated commutator segments, in such a manner that the coil is a continuous one, endless as in the Gramme machine, but not wound or connected in the same manner. When the armature is caused to rotate, a current is induced in the armature-coils, and the magnet is excited, upon the principle of mutual action already described.

The smallest-sized Häfner-Alteneck machine is $698^{mm}$ in length, $572^{mm}$ wide, and $233^{mm}$ high; the drum is $388^{mm}$ long, and carries 28 wire coils and a commutator divided into 56 parts. Its weight amounts to 115 kilogrammes; the maximum velocity of the drum, 900 revolutions per minute; and the intensity of the light produced, 1,400 standard candles. One and a half horse-power is required to run it. The medium-sized machine differs in construction but slightly from the above. It is $757^{mm}$ in length, $700^{mm}$ wide, and $284^{mm}$ high; the drum has a length of $456^{mm}$, and is also wound with 28 coils. The commutator is, therefore, also composed of 56 pieces, upon which wire collecting brushes are made to press. The machine weighs 200 kilogrammes, and produces, at its maximum velocity of 700 revolutions per minute, a light of 4,000 candles, and absorbs three and one-half horse-power.

In the South Foreland lighthouse experiments, conducted by Prof. Tyndall, the relative efficiency of the Gramme and the Häfner-Alteneck machines was made the subject of special investigation. It was found that at a speed of 420 revolutions per minute, absorbing 5.3 horse-power, the Gramme machine developed a light of 758 candles per horse-power. The largest Häfner-Alteneck machine, at 480 revolutions and absorbing 9.8 horse-power, developed 911 candles-light per horse-power; while a smaller machine, at 850 revolutions per minute, absorbing 3.5 horse-power, developed 954 candles-light per horse-power. A second small machine developed for a brief period 1,254 candles-light per horse-power.

In another form of the New Siemens machine (Fig. 20), the iron armature core is stationary, and the coils of wire are fixed upon and rotate with a cylinder of German silver surrounding, but not touching, the core. In Dr. Schellen's description of this form of generator, which is most complete, he illustrates the fact that when the armature-core moves in a magnetic field, such motion develops induced, or so-called Foucault, currents, which, if not conducted away, become transformed into heat, and thus, according to the circumstances of the case, give

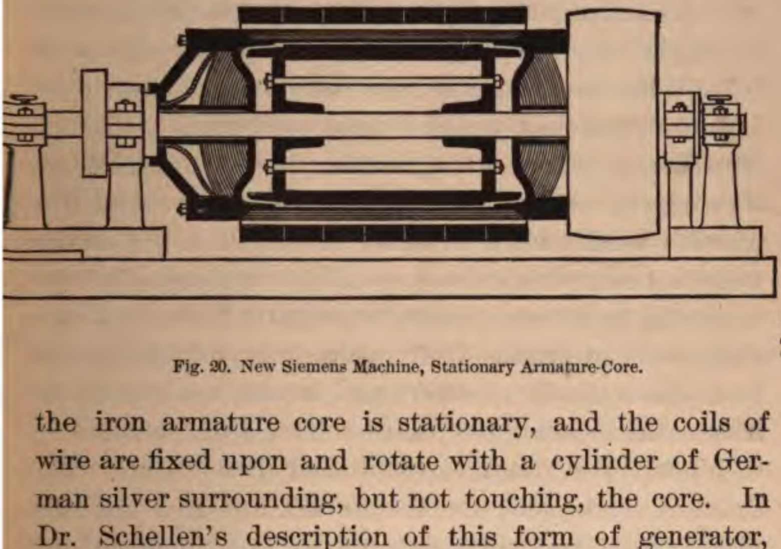


Fig. 20. New Siemens Machine, Stationary Armature-Core.

rise to a considerable heating of the metallic bodies in motion. As long, therefore, as the iron core revolves with the coiled drum through the magnetic field, these currents are not to be avoided, though they may be diminished to some extent by constructing the armature of coils of iron wire instead of massive iron. It was, therefore, determined to secure the iron armature inside the drum, and so prevent it from taking part in the motion of the latter. As a matter of course, this renders the construction of the drum much more complicated, especially when it is considered that the long drum, with its surrounding coils of wire, has to be moved through the narrowest possible space between the polar faces of the electro-magnet and the stationary iron core.

In the engraving, which is composed from Dr. Schellen's work, we have a horizontal section of the machine, showing the thin German-silver drum upon which the wire is wound. Each terminal face of the drum carries a short tube, which tubes form the trunnions of the drum and lie in boxes provided with oil-cups. An iron shaft, secured by means of screws in its supporting pillars, passes through these tubes into the interior of the iron armature, where, by means of two disks bolted to each other, the armature is fastened to the shaft. The drum is surrounded on the outside, at two opposite places, for about two-thirds of its circumference and over its entire length, by the two curved polar faces of the magnet. These are placed as closely as possible to the wire surrounding the German-silver drum, and form, with the stationary hollow iron interior core, a narrow annular space, constituting the magnetic field, through which the drum, with its surrounding wires, must pass in rotation with the utmost possible freedom. For several reasons this form of the New Siemens machine has failed to yield results sufficiently satisfactory to warrant its manufacture in place of the simpler form in which the iron cylinder rotates with the surrounding coils.

The defect of the Häfner-Alteneck machine, as was the case with the Wilde machine, is found in excessive heating of the armature, and this is frequently so great as to destroy the insulations. Indeed, injurious heating is the defect of nearly all generators, for the local action of dynamo-machines is analogous to the local action of galvanic batteries, and the temperature must continually increase until the loss by radiation and convection equals the amount of heat produced. If a machine, through running, acquires a high temperature with a proper external resistance, its efficiency is low, and any heating whatever reduces its efficiency. Thus the large Brush machine at the Franklin Institute, in running 25 minutes, increased in temperature from 73½° to 88° Fahr., and in its internal resistance from .483 to .493 ohm. In machines of the Häfner-Alteneck type the heat produced is much more marked and injurious, and the various improvements upon or modifications of the same, as in the Hochhausen, Thomson and Houston, Weston, Edison, and the Sawyer generators, have in view the obviation of this evil.

The Edison Machine (Fig. 21) has recently attracted much attention. The compound electro-magnet of Siemens is replaced by a long and powerful simple electro-magnet, and in constructing the armature the hollow drum is modified. In efficiency the Edison generator, properly constructed, would seem to be equal to any of the Häfner-Alteneck form, although we have no data upon which to base a conclusion. The armature is

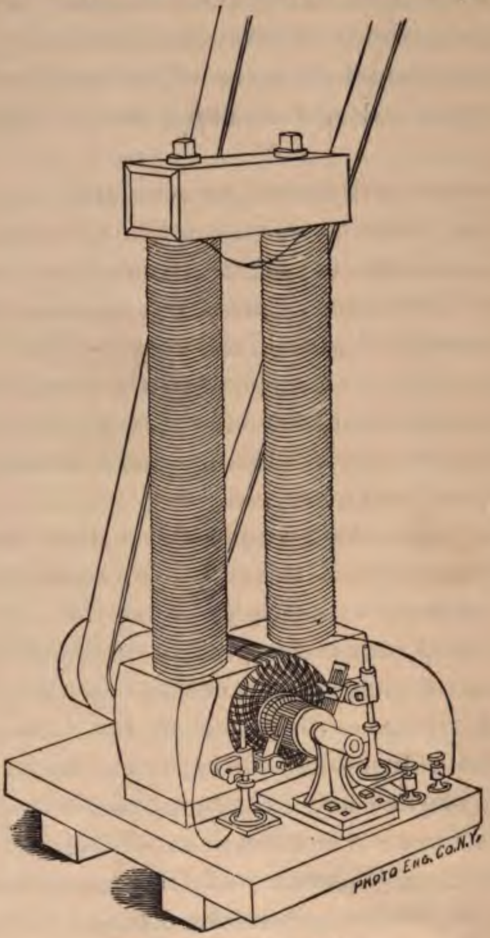


Fig. 21. The Edison Machine.

constructed in two ways. In the first, of which Fig. 22 is a sectional end view, a helix of iron wire, wound like thread upon a spool, surrounds a wooden or other diamagnetic roll. This helix constitutes the core of the armature. Over it the insulated coils are wound as shown in Fig. 23.

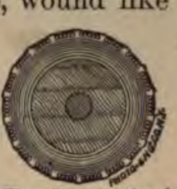


Fig. 22. Sectional End View of Armature.

In the second form of Edison armature, it is composed of a large number of thin, soft-iron flanges, similar to those used in the Maxim machine, and a free circulation of currents of air, to avoid destructive heating, is provided.

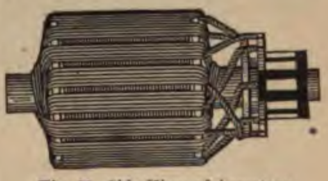


Fig. 23. Side View of Armature.

In the Sawyer machine, of which Fig. 24 is an illustration, the compound magnet of Siemens is discarded, and a simple Wilde electro-magnet of cast-iron is substituted therefor. To secure the maximum of magnetic power, the limbs of the magnet increase in thickness as they approach the base (Fig. 25). To the upper ends of the magnet limbs cast-iron polar extensions are bolted.

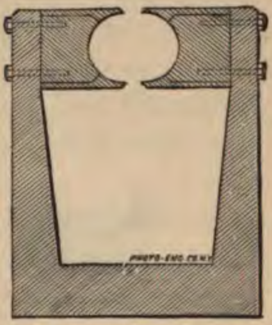
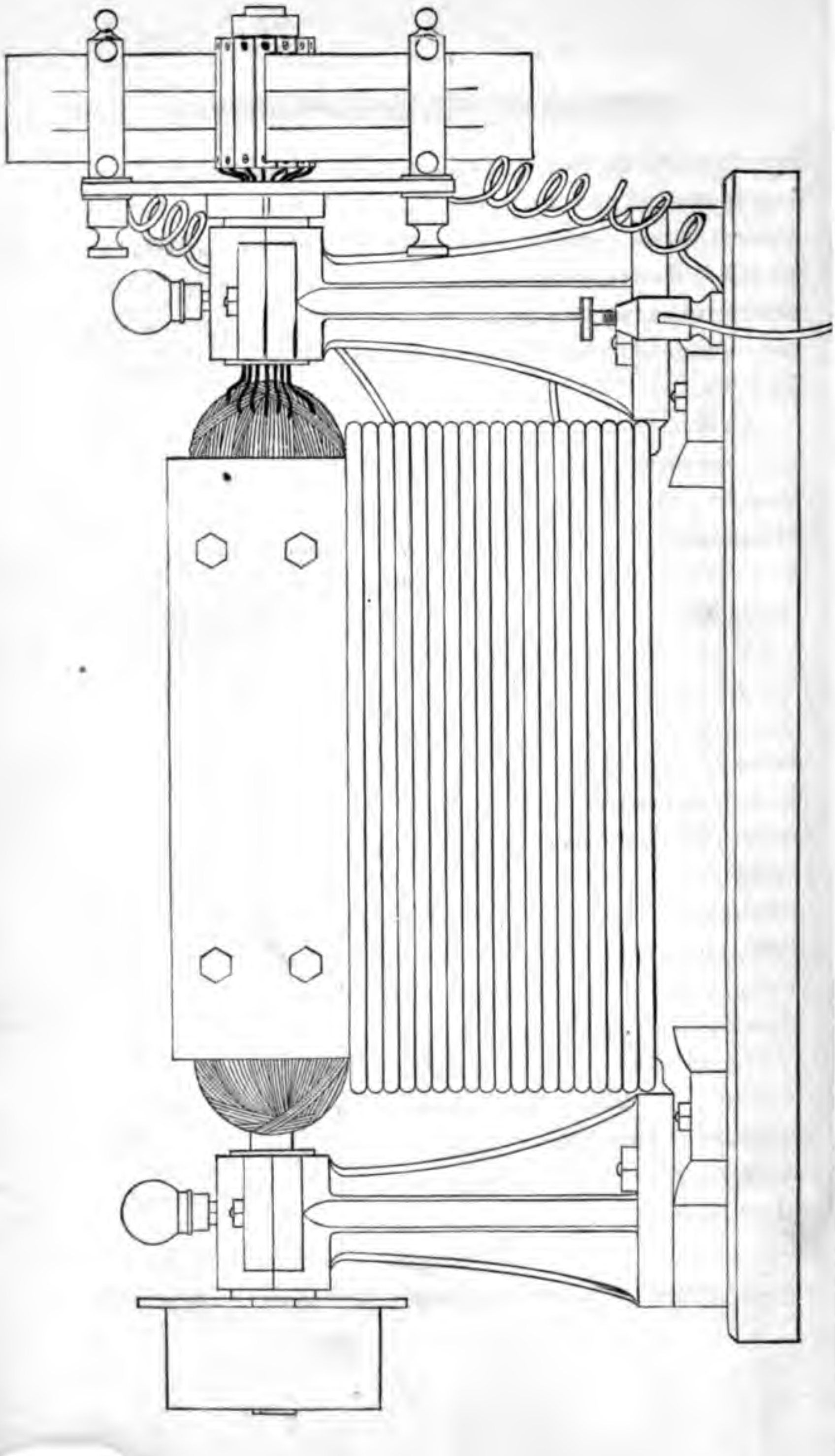


Fig. 25. End View of Magnet.

The generator shown in the illustration is the smallest size of machine, the armature being 2 inches in diameter, and, as in other similar machines of small size, the armature-core consists of a substantially solid roll of malleable iron. In large machines the armature,



like that of the Häfner-Alteneck machine, is in the form of a hollow drum.

To prevent heating, the malleable iron roll is constructed as shown in the sectional end and side views, Fig. 26. Around a series of wrought-iron tubes, B, the iron A is cast, and over the ends are secured malleable iron caps, D. The shaft C is hollowed out a portion of its length from each end, and provided with openings into the spaces enclosed by caps D. All the joints are water-tight. By means of a closely-fitting, though loose, entrance-pipe, a small stream of water is let into one end of the shaft and passes in the direction of the arrow into the cap space, thence through tubes B, and outwardly through the opposite cap space, the hollowed shaft, and a closely-fitting waste-pipe.

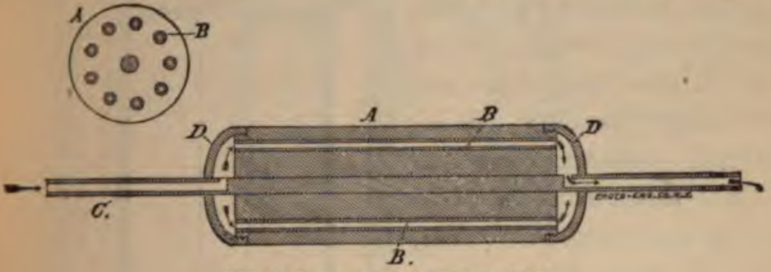


Fig. 26. Construction of Armature-Core.

The armature of the larger machines is illustrated in Figs. 27 and 28. Upon the shaft A is fixed a brass cylinder, B, which is water-tight as to the inner chamber. Over this cylinder, and leaving a space between, is fixed the iron drum D, whose caps, C, are keyed to the shaft. In the annular space thus formed between cylinder B and drum D the water circulates.

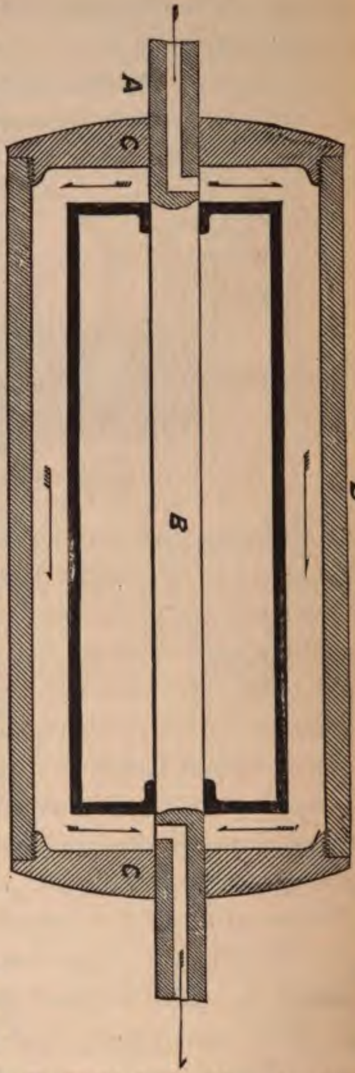


Fig. 27. Side Section of Large Armature.

In principle the same as the Häfner-Alteneck machine, it is not surprising that this generator should have yielded as good results; but the temperatures maintained while doing work have been of an unexpected character. In internal resistance the machine varies from .25 of an ohm to 5. ohms, according to the work to be done; and the distance between the periphery of the iron of the armature and the polar faces of the magnet is from five-sixteenths of an inch to one and one-eighth inches, according to the size of the machine. Each polar face covers one-third of the periphery of the armature when wound with the induction helices.

The No. 1, or smallest size of machine, driven at a speed of 1,000 revolutions per minute by a belt one inch in width, yields a light by the voltaic arc of 500 candles, and by incandescence

275 candles. No deduction is made for the element of friction, the percentage of which in small machines is large.

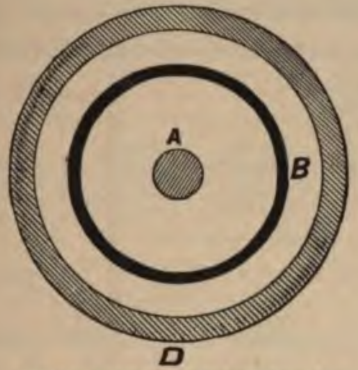


Fig. 28. End Section of Large Armature.

The following table, compiled from a series of tests made in November, 1880, shows the average temperatures observed at the beginning and end of three hours' running, operating a closed circuit:

| No. of machine. | Internal resistance of machine, in ohms. | External resistance of circuit, in ohms. | Temperature of machine at beginning of run, in degrees Fahr. | Temperature of armature at end of run, in degrees Fahr. | Temperature of magnet-coils at end of run, in degrees Fahr. |
|---|---|---|---|---|---|
| 1 | .25 | .25 | 80° | 71° | 84° |
| 2 | 1.15 | .75 | 76° | 73° | 82° |
| 3 | 1.5 | 1.5 | 79° | 54° | 81½° |
| 3 | 1.5 | .75 | 79° | 65° | 85° |

Reduction of the temperature of the armature below that of the surrounding air was so entirely unexpected that on November 22 a prolonged test of the No. 2 machine, wound with a different size of wire, was made. The internal resistance of the machine was found to be

1.27 ohms, and the resistance of the external circuit .9 ohm, making the total resistance 2.17 ohms. The duration of the test was from 9.30 A.M. until 9 P.M. Observations were carefully made both at the beginning and end of the run, and at intermediate intervals, with the following result:

| Temperature of machine at start. | Average temperature of laboratory. | Average temperature of water before entering armature. | Average temperature of water on leaving armature. | Average temperature of armature. | Average temperature of magnet-coils |
|---|---|---|---|---|---|
| 73° F. | 73½° F. | 58° F. | 67° F. | 67½° F. | 76° F. |

In every case the temperature of the armature is found to decrease, although the larger sizes of machines have not been subjected to thermometric measurement.

There is some diversity of opinion regarding the best method of winding the Häfner-Alteneck armature. Very little is generally known about the subject, except that there are several methods, none of which have ever been made very clear. A method of winding, substantially as good as any, and one that has been used in both the Edison and the Sawyer machines, is illustrated in Fig. 29.

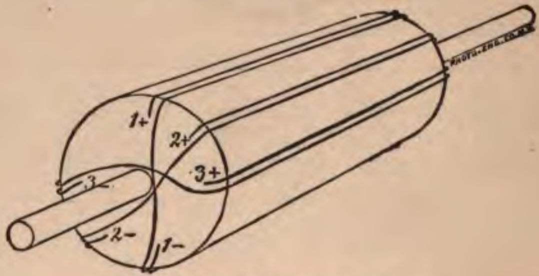


Fig. 29. Method of Winding Armature.

The armature is divided into, say, 28 equal sections, and the requisite number of convolutions of the wire, always the same, is wound in 14 separate coils longitudinally around the drum, closely together, and with the

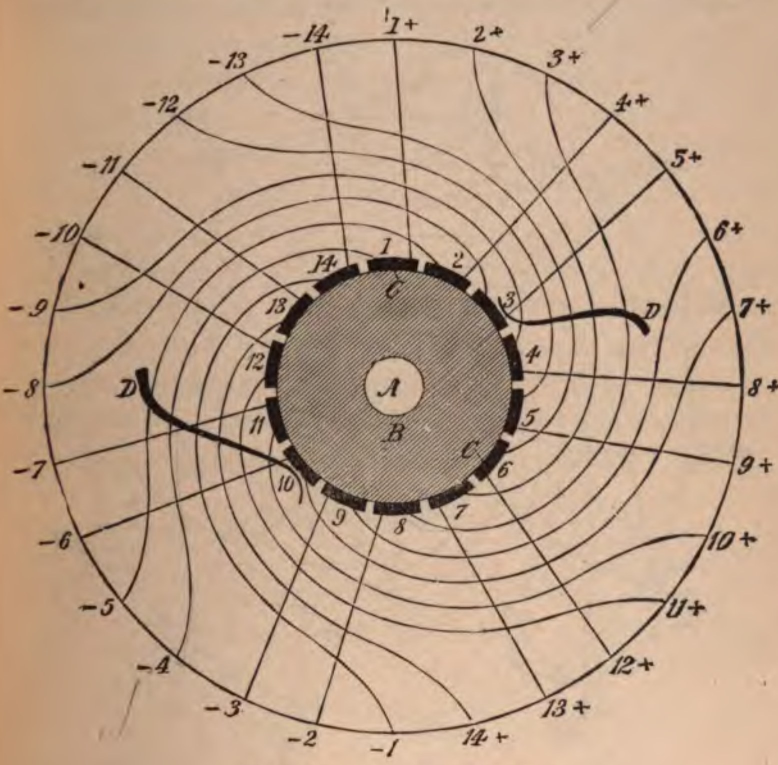


Fig 30. Connections of Armature-Coils.

ends left free, in the manner shown. The coil No. 2 follows coil No. 1, and coil No. 3 follows coil No. 2, and so on until the 28 sections (14 on each half of the drum) are filled, the + sign representing the starting end and the — sign the termination of the wire composing each coil. Covering of the drum with asbestos-paper to ensure proper insulation is advisable, and in order to facilitate the winding it is useful to insert temporary guiding-pins at the ends and middle of the drum, on the lines dividing the sections. Accurate laying of the wire is essential. After winding, the coils are bound to the drum by fine brass wires wound so as to form a band around it, and soldered. There should be several such bands at different points along the length of the

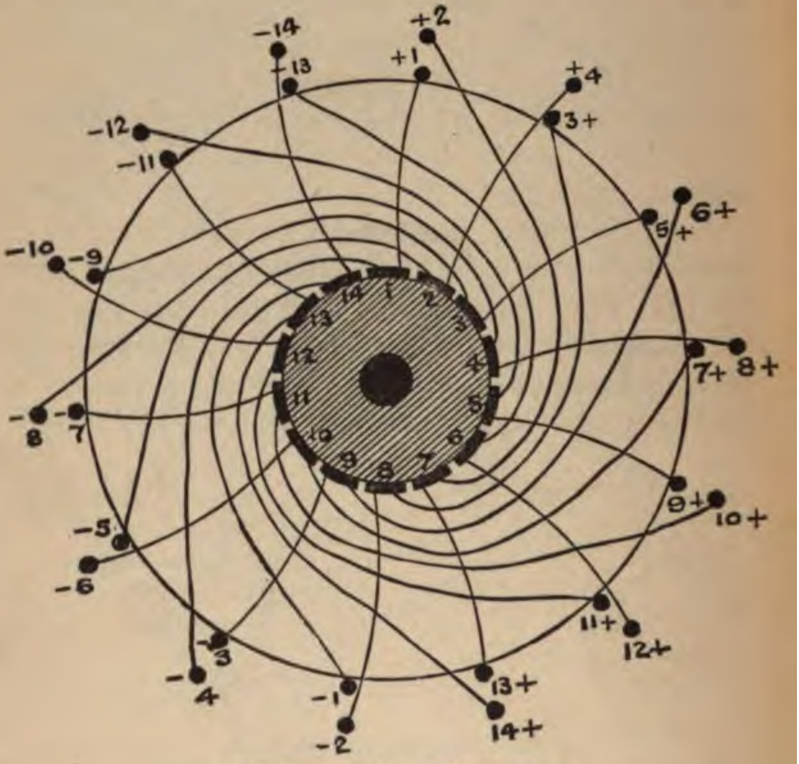


Fig. 31. Superposed Coils and Connections.

drum, protected from contact with the wire of the coils by interposed bands of mica. To the free ends of the coils, through a sleeve on the shaft of the machine, the fourteen commutator segments are connected as shown in Fig. 30, in which A is the shaft, B insulating disk, C C commutator segments, and D D collecting brushes.

In some cases it is preferable to superpose coil No. 2 upon coil No. 1, etc., as shown in Fig. 31, in which case the drum is divided into fourteen sections. The connections of the commutator segments, as will be seen, remain the same.

The collecting brushes bear seriatim upon commutator segments 1, 8; 2, 9; 3, 10; 4, 11; 5, 12; 6, 13; 7, 14; 8, 1; 9, 2; 10, 3; 11, 4; 12, 5; 13, 6; 14, 7; and in each of the respective positions the circuit of the armature-coils, the sections of which now constitute a continuous, endless conductor, is as shown on page 52:

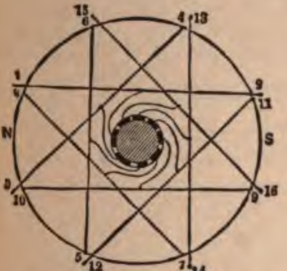


Fig. 32. Herr Frölich Winding.

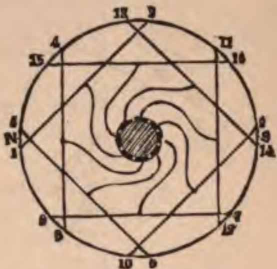


Fig. 33. Brèguét Winding.

Generally, it is advisable to divide the armature-coil into as many sections as may be consistent with the practical mechanical construction of the armature and commutator, in order that the coil may cut the lines of magnetic force the greatest possible number of times in a single revolution of the armature.

| Segment of commutator in contact with 1st brush. | Direction and division of the multiple circuit from brush to brush. | Segment of commutator in contact with 2d brush. |
|---|---|---|
| 1 | 1 + 14 — 11 — 10 — 7 — 6 — 3 —<br>4 — 5 — 8 — 9 — 12 — 13 — 2 + | 8 |
| 2 | 4 + 1 + 14 — 11 — 10 — 7 — 6 —<br>5 — 8 — 9 — 12 — 13 — 2 + 3 + | 9 |
| 3 | 5 + 4 + 1 + 14 — 11 — 10 — 7 —<br>8 — 9 — 12 — 13 — 2 + 3 + 6 + | 10 |
| 4 | 8 + 5 + 4 + 1 + 14 — 11 — 10 —<br>9 — 12 — 13 — 2 + 3 + 6 + 7 + | 11 |
| 5 | 9 + 8 + 5 + 4 + 1 + 14 — 11 —<br>12 — 13 — 2 + 3 + 6 + 7 + 10 + | 12 |
| 6 | 12 + 9 + 8 + 5 + 4 + 1 + 14 —<br>13 — 2 + 3 + 6 + 7 + 10 + 11 + | 13 |
| 7 | 13 + 12 + 9 + 8 + 5 + 4 + 1 +<br>2 + 3 + 6 + 7 + 10 + 11 + 14 + | 14 |
| 8 | 2 — 13 + 12 + 9 + 8 + 5 + 4 +<br>3 + 6 + 7 + 10 + 11 + 14 + 1 — | 1 |
| 9 | 3 — 2 — 13 + 12 + 9 + 8 + 5 +<br>6 + 7 + 10 + 11 + 14 + 1 — 4 — | 2 |
| 10 | 6 — 3 — 2 — 13 + 12 + 9 + 8 +<br>7 + 10 + 11 + 14 + 1 — 4 — 5 — | 3 |
| 11 | 7 — 6 — 3 — 2 — 13 + 12 + 9 +<br>10 + 11 + 14 + 1 — 4 — 5 — 8 — | 4 |
| 12 | 10 — 7 — 6 — 3 — 2 — 13 + 12 +<br>11 + 14 + 1 — 4 — 5 — 8 — 9 — | 5 |
| 13 | 11 — 10 — 7 — 6 — 3 — 2 — 13 +<br>14 + 1 — 4 — 5 — 8 — 9 — 12 — | 6 |
| 14 | 14 — 11 — 10 — 7 — 6 — 3 — 2 —<br>1 — 4 — 5 — 8 — 9 — 12 — 13 — | 7 |

The method of winding the armature devised by Herr Frölich (Fig. 32) comprises sixteen vertical conductors arranged in pairs at the point of a regular octagon, and crossing the octagon by the diagonals at one end of the armature, and by long chords, crossing in the form of an eight-pointed star, at the other. In the method discovered by M. Brègnét (Fig. 33), the portions of the coils which cross the ends of the armature to unite the sixteen vertical wires cross the octagon along short chords.

# CHAPTER IV.

## INCANDESCENT LAMPS.

PRODUCING light by heating a poor conductor of electricity to incandescence is a favorite conception of experimentalists, and numerous attempts have been made toward its practical reälization. In nearly every instance these attempts have resulted in failure, not so much because of any inherent defect of principle as because of imperfections in the details of construction and operation.

Lighting by incandescence involves a principle as simple as lighting by the voltaic arc. The conductor rendered luminous is of poor conductivity, or, in other terms, of high resistance. The resistance of the wires connecting it with the generator of electricity may be disregarded. Therefore the current generated is divided between the generator and the poor conductor exactly in proportion to their respective resistances; and as the latter is contained in small compass, the current is concentrated at a small point and there produces calorific effects sufficient to yield light.

When a body is at the temperature of 1,000° C. we have the heat-rays:

At 1,200° we have the orange rays.
“ 1,300° “ “ “ yellow rays.
“ 1,500° “ “ “ blue rays.
“ 1,700° “ “ “ indigo rays.
“ 2,000° “ “ “ violet rays.

Above 2,000° C. we have all the rays of the sun. In incandescent carbon lighting the conductor is raised to a temperature much in excess of 2,000°.

Many conductors may be employed in the production of light by incandescence; and it is a curious fact that experimentalists have almost invariably followed a beaten course, passing from one metal to another: from platinum to iridium and iridio-platinum; from the metals to carbon-coated and intermixed asbestos and other refractory materials; and finally to carbon alone. As carbon, pure and simple, has been clearly determined to be the only suitable substance, we shall leave out of consideration all other conductors of electricity.

There are two types of incandescent lamps in use, those which burn in the air and those in which the luminous conductor is enclosed in a globe exhausted of air or containing an atmosphere of nitrogen or other gas for which carbon at high temperatures has no chemical affinity. The open-air lamp is subject to so many objections that it is doubtful whether it will ever be successfully employed; but the efforts of Renier and Werdermann have done much towards reducing it to practical form. The Renier lamp (Fig. 34) consists of a long pencil of carbon continuously fed between an elastic contact to a bearing upon a carbon roller at a point between the vertical and the horizontal. The upper or elastic contact compresses the pencil laterally, and one terminal of the conducting wire is connected with this contact. The other terminal is connected with the carbon roller. The pencil, being consumed at the lower extremity more rapidly than at any other place, diminishes in length, and this diminution is compensated by the continuous downward feeding of the pencil. Rotation of the carbon roller to carry away dead fragments of carbon is obtained from the tangential component of the pressure of the pencil on the periphery of the roller.

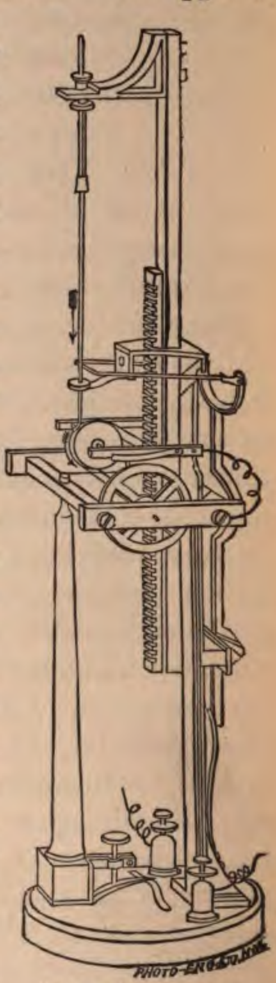


Fig. 34. Renier's Lamp.

The Werdermann lamp (Fig. 35) is the reverse of the Renier lamp in construction and operation. In this lamp the carbon pencil is fed upward, through an elastic contact, by means of a weight or spring, against a solid stationary block of carbon.

Both the Renier and the Werdermann lamps, under proper conditions, should yield a higher percentage of light per horse-power than lamps in which the carbon is protected from oxygen; but in both these lamps the constant renewal of the carbon pencil and points of contact necessary are objections to be surmounted.

The earliest attempt to isolate an incandescent carbon conductor from oxygen appears to have been made by

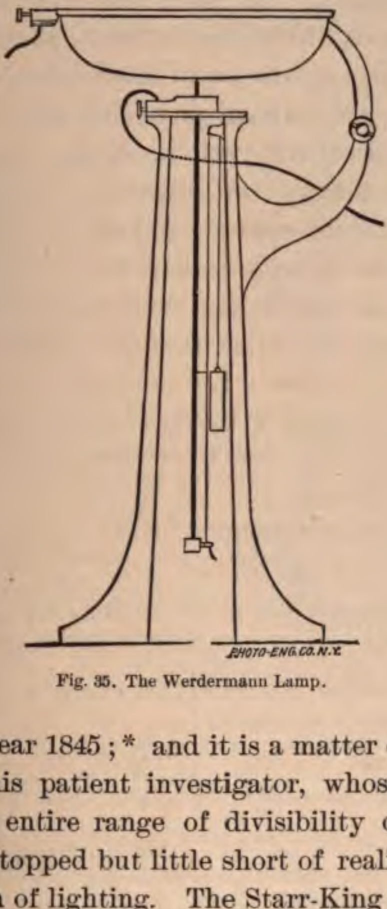


Fig. 35. The Werdermann Lamp.

Starr in the year 1845;* and it is a matter of some surprise that this patient investigator, whose conception included the entire range of divisibility of the light, should have stopped but little short of realizing a practicable system of lighting. The Starr-King burner (Fig.

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* Starr-King; English patent No. 10,919, 1845.

36) consists of a conducting wire, D, sealed in the glass of a Toricellian vacuum-tube, and connecting with a carbon rod, A, whose lower extremity is in contact with a second conductor resting in the quicksilver. The bar B, of porcelain, serves as a support for the apparatus. For several reasons this lamp could not have been a successful one, as will be made clear in another chapter.*

In 1873, nearly thirty years later, came the invention of Lodyguine,† a Russian physicist, who was awarded, during the subsequent year, the great prize of the St. Petersburg Academy of Sciences. The Lodyguine burner consisted of a single rod of carbon diminishing in section at the incandescent part; and two or more of these rods were placed in a globe provided with an exterior rheotome, in order that the current might be passed through a fresh carbon when one should have been destroyed. Unaccountably, Lodyguine has been severely criticised by many writers, who have pronounced his apparatus the least practical and the least studied of all; whereas it was the most practical and the most studied of all that had preceded it, for Lodyguine recognized the value of a perfect connection with the incandescent portion, such as results from enlargement of the carbon at the points of contact with the

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* The Starr-King system of lighting included a generator of electricity some of the devices of which are variously used at the present day. The following summary of the leading points of Starr's English patent, taken out by King in 1846 (No. 11,188), and entitled "Improvements in the Production of Magneto-Electricity," is of interest:

1. The principle of the machine consists in revolving between the poles of permanent magnets, arranged radially, a disk having near its edge bobbins with their axes parallel to the axis of rotation.

2. Winds around the iron cores a continuous flat strip of copper, inserting cotton between each layer to insulate.

3. Collects the current from the separate bobbins with separate springs, to allow of subdivision, if necessary.

4. To prevent neutralizing currents being induced in the brass or other metallic plate which forms the wheel carrying the armatures, a saw-cut is made from the edge to the hole in which the armature is inserted.

5. Attaches a soft-iron bar to the inducing magnets, so that they may each act a second time on any armature during each revolution.

† Meanwhile both Shepard in 1850, English patent No. 13,302, and Roberts in 1852, English patent No. 14,198, invented and experimented with incandescent carbon lamps.

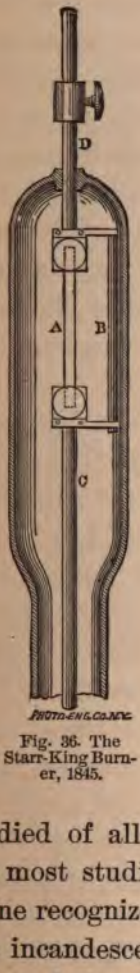

Fig. 36. The Starr-King Burner, 1845.

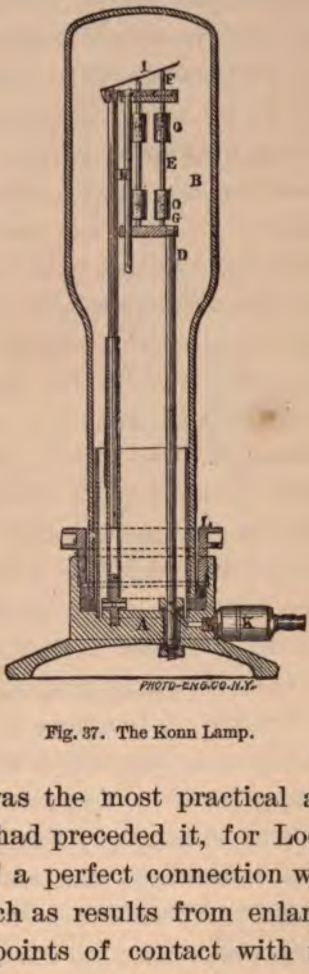

Fig. 37. The Konn Lamp.

conductors leading to it, and he provided for the inevitable destruction of the rod by arranging another to take its place.

After Lodyguine came Konn and Kosloff, whose inventions do not differ essentially, although the Konn lamp of 1875 (Fig. 37) was perhaps the more practicable. This lamp consists of a base, A, in copper, on which are fixed two terminals to which the conductors are fastened; two bars, C D, in copper; and a small valve, K, opening only from within outwards. A globe, B, expanded at its upper part, is clamped to the base by means of a collar, L, pressing on soft rubber washers. One of the vertical rods, D, is insulated from the base, and communicates with a terminal, also insulated. The other rod, C, is constructed in two parts: (1) of a tube fixed directly upon the base and in electrical connection therewith; and (2) of a copper rod split for a part of its length, whereby is obtained sufficient elasticity to permit the rod to slide freely and yet be held in place in the tube. Carbon pencils, E, are placed between two small plates which crown the rods. Each pencil is introduced into two small blocks, O, also of carbon, which receive the copper rods F G at their extremities. The rods G are equal in length, and the rods F are of unequal length. A hammer, I, is hinged on the bar C, and makes connection only with a single pencil of carbon at once.

When the lamp is placed in circuit, a pencil of carbon, E, is traversed by the current; and when this pencil is consumed and drops out of place, the hammer, I, makes connection with another pencil; when all the carbons have been consumed the hammer rests upon the copper rod H, and the circuit is not interrupted. According to M. Fontaine, the maximum light obtainable from a Konn burner is equal to about 175 candles. The carbon is protected by partially exhausting the air and depending upon the carbon monoxide, subsequently formed, to preserve it from further change—an error in calculation which it is difficult to understand, and the fallacy of which is proved by the results. The average duration of the first pencil is about twenty minutes.

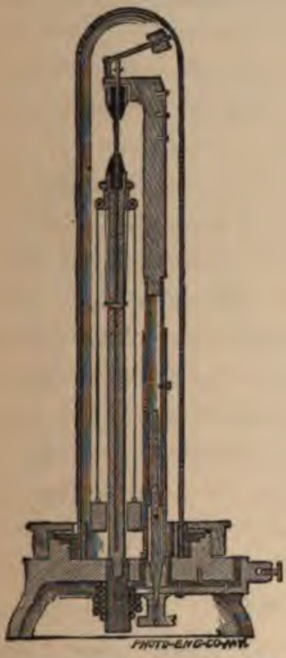

Fig. 38. The Bouliguine Lamp.

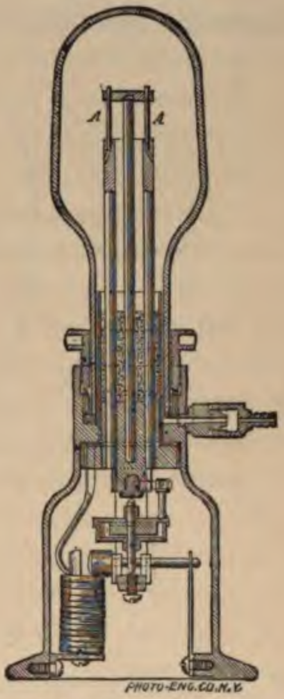

Fig. 39. Fontaine's Lamp.

The succeeding pencils have each an average life of two hours.

Next in practical order comes the Bouliguine lamp (Fig. 38), in which a long pencil of carbon is fed upwards, as in the Werdermann lamp, through an elastic contact, in this case controlled electro-magnetically. The sealing of the globe is effected, as in the Konn lamp, by the lateral pressure of soft rubber washers.*

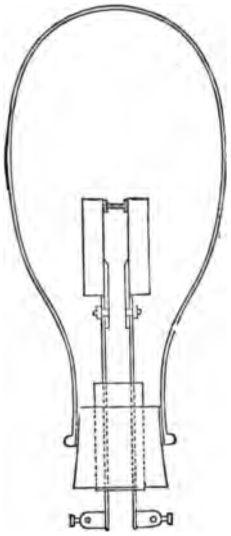

Fig. 40. Farmer's Lamp, 1879.

The last of these old lamps of which there is record is the invention of M. Fontaine (Fig. 39), in which the carbon pencils, A A, are held in rigid contacts. No allowance is made for expansion or contraction of the conductors. In this lamp, as in Lodyguine's, a fresh pencil is brought into circuit by an exterior rheotome when one has been consumed.

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* Carbon-holders, made in the form of long tubes and filled with long carbons, were first employed by Staite (English patent No. 12,212 of 1848), who, with his associate, Edwards, was much in advance of the day in which he worked.

Among all these lamps that of Konn maintains its supremacy; and it must be confessed that, considering the time and means devoted to the solution of this problem in European countries, the product is insignificant.

The lamp illustrated in Fig. 40, which was patented by Farmer, March 25, 1879, has not progressed beyond the stage of laboratory experiment. It is perhaps less practical than the lamps of Konn and others, in these respects: that the incandescent rod or pencil is held between large blocks of carbon in such a manner as to greatly obscure the light; and that the sealing is effected by means of a rubber stopper through which pass the conducting supports, which, being good conductors of heat, must inevitably cause the lamp to unseal.

# CHAPTER V.

## CARBONS FOR INCANDESCENT LIGHTING.

BEFORE entering upon a further survey of the field of incandescent lighting, it is well that we should pause to consider the primal element of all incandescent lamps—the luminous carbon conductor. Its requirements are simply expressed. In cross-section it must be uniform and in homogeneity perfect. The denser and harder the carbon the more lasting it proves to be; and density, hardness, and homogeneity in the carbon are therefore the elements, or a part of them, of success. Before the time of Foucault, who substituted gas-retort carbon for wood charcoal, the voltaic arc was little more than a laboratory toy; and thus with incandescent lighting, so long as the luminous conductor is confined to the product of the gas-retort its uses must be confined to the laboratory.

One of the earliest methods of preparing artificial carbons, and that in most general use at the present day, consists in reducing coke to a fine powder and thoroughly incorporating it with molasses or other glutinous hydrocarbon substance. The resultant mixture is pressed into moulds and baked, and afterwards placed in a concentrated solution of the same hydrocarbon, and, when thoroughly saturated, again baked; and so on until it acquires the requisite solidity and smoothness. Such carbons are imperfect, since they contain many impurities.

By the Jacquelin process carbon is produced which, in purity, density, hardness, and homogeneity, is all that could be desired. M. Jacquelin, with pure hydrocarbons, closely imitates the processes of the gas-retort, decomposition of the compound gases being accomplished in a highly-heated porcelain tube, upon the interior surface of which the carbon is deposited. The objection to this process consists in the difficulty of reducing the mass thus formed to the shape of rods or pencils, as the carbon obtained is so hard that it can be cut only with the greatest difficulty.*

The best artificial carbons for incandescent lighting that we have obtained are made by the Carré process, and supplied by M. Brèguét in mechanically perfect round pencils of from eight to twenty inches in length, and almost any desired diameter in millimetres; but in these carbons there is room for extensive improvement which, no doubt, M. Carré will turn to advantage. According to Fontaine, the process of manufacture is as follows: A composition, consisting of very finely powdered coke, calcined lamp-black, and a syrup formed of twelve parts of gum and thirty of cane-sugar, is thoroughly ground and intermixed, and sufficient water is added to give the required consistency. Thus prepared the paste is compressed and passed through a die-plate, whereby the pencil is formed. Subsequently the pencil is subjected to a high temperature in a crucible, and by various operations and repetitions of the heating the requisite density and hardness are obtained. The arrangement of the pencil for baking, after forming, while yet in a pliable condition and without permitting it to twist or bend, is one not fully understood; and all attempts in this country towards duplicating the manufacture have signally failed. Pencils of one thirty-second of an inch in diameter and nine inches in length, made expressly for us, are as absolutely straight and regular as a wire under tension.

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* Within a few days we have experimented with a smooth disk of celluloid, revolving at a high rate of speed, and we find that by means of it the hardest retort-carbon is as easily and smoothly cut as so much hard rubber. This would seem to promise a similar result with Jacquelin carbons.

The drawn or moulded pencils are primarily placed in a horizontal position on a bed of coke-dust in crucibles, each layer being separated from its neighbor by an intervening sheet of paper. Secondly, a layer of coke-dust is spread over the carbons; and, lastly, the whole is covered by silicious sand. Having been kept at a cherry-red heat for four or five hours, the carbons are removed to a vessel of boiling-hot, concentrated caramel or sugar-cane, and there left for two or three hours, the syrup being alternately cooled and heated several times, in order that it may completely permeate the pores of the carbons. Subsequently the syrup is drawn off, and any sugar adhering to the surface of the carbons is removed by immersion in boiling water. Finally, after drying in an oven, whose temperature attains to 80° C. only in the course of twelve to fifteen hours, the baking operation is repeated. Upon the number of repetitions of this process, to a certain extent, depends the value of the carbons, which, specially manufactured, are marvels of purity, tenacity, density, and homogeneity.*

* The following synopsis of old English patents relating to electric-light carbons, taken from Col. Bolton's report, will doubtless prove of interest:

1846. **Greener and Staite**, 11,076. "Certain Improvements in Ignition and Illumination."

Uses lamp-black, charcoal, or coke, already purified from sulphur and metallic mixtures by the application of electricity in accordance with the process patented by Jabez Church in 1845; digests in nitro muriatic acid; washes several times in water or in some weak alkaline solution, or carburetted alkaline solution, finally with distilled water; then dries and presses with hydraulic screw, or fly-press, into cylinders, and when necessary exposes to intense heat in a furnace for twenty-four hours.

1846. **Staite**, 11,449. Takes equal quantities of coal of a medium quality (neither too rich nor too poor) and of that purified description of coke known as "Church's Patent Coke"; powders and compresses in close sheet-iron moulds until solid, then plunges into concentrated solution of sugar, and when sufficiently dry subjects it for several hours in a close vessel containing charcoal at an intense white heat.

1847. **Staite**, 11,783. In addition to pressing, also heat, and when hot plunge into sugar melted by heat without the aid of any liquid. Then cool and place in a closed vessel containing pieces of charcoal heated to a white heat, and keep there for many hours, or even two or three days; or the whole mass may be a second time immersed in melted sugar and the process repeated.

He says, also, that electrodes made of gas-retort carbon frequently contain iron, which makes them split and not give out so much light. They may be much improved by heating to a white heat in a closed vessel for some days.

1848. **Staite**, 12,212. Prefers to use, 1st, plumbago powder having iron, etc., extracted by washing and warming in acids; 2d, lamp-black; 3d, charcoal powder; 4th, powder of carbonaceous concrete which is deposited in gas-retorts; or, 5th, sifted grains of this material. Mix any one of these with brown sugar, melt and boil (without water) until stiff, press when hot in iron moulds lined inside with paper, chalk, or plaster-of-Paris to prevent adherence and to allow for escape of the gas, the moulds having holes for the same purpose. Heat slowly until a red heat is obtained, at which temperature keep them for some time, then take out and put in upright crucibles with lute; gently raise to a white heat, at which temperature keep them for some time, and then allow them to cool.

The lack of a better carbon than retort carbon di-

1848. Le Molt, 12,219. "Constructing Electric or Galvanic Piles for obtaining Electric Light."

Take one part of coal, coke, or charcoal, three parts of carbon obtained from gas-retorts, ground fine, and one of tar; mould and press, dry in the shade, heat gradually in a nearly closed retort until brought to a red heat, at which temperature keep the retort for thirty-six hours, when cool slowly.

Makes the carbon disks used by him in his electric lamp from gas-retort carbon, cut into the right shape, and purified by solution in a mixture of nitric and muriatic acids for twelve hours, afterwards in fluoric acid for twelve hours.

1852. Roberts, 14,198. "Improvements in the production of Electric Currents in obtaining Light," etc.

Mixes five per cent. of lime with materials of electrodes, to increase the brilliancy of the light.

1852. Jackson, 14,330. "Improvements in producing Artificial Light," etc.

Hollows out top of lower carbon and introduces mercury or platinum into the recess.

1853. Binks, 119. "Improvements in producing Electric Light." Provisional protection only.

Subjects lignite to destructive distillation in closed vessels.

Covers metal with tar, pitch, bitumen, asphalt, and rosin, or mixtures of finely-pulverized charcoal or lamp-black, with some adhesive material, which on being dried or strongly heated leaves a residue of solid or compact carbon.

Or drills holes in carbon and inserts metal rods, or attaches a veneering of charcoal to metal.

1853. Staite, 634. Boils carbon in oil or other fatty substance, and bakes.

1857. Harrison, 588. "Improvements in obtaining Light by Electricity."

Pieces of metal or other material are placed in gas-retorts, or in tubes connected therewith, for the purpose of receiving a deposit of gas carbon. Or a combination of metal powder and plumbago, or other form of carbon, may be formed into electrodes by compression. Proposes to insert other substances in the powder in order to color the light.

1858. Hunt, 282. "Improvements in Means for Producing the Electric Light."

The residuum from the distillation of tar or pitch is reduced to an impalpable powder, and mixed with tar or other hydrocarbon; the electrodes are then moulded, heated red hot, immersed in tar and again heated, and so on until the required density is obtained.

rected our attention to new processes of manufacture, resulting in the granting of Letters-Patent to Sawyer & Man in January, 1879, for a process believed to be new in physics. In many experiments previously made, incandescent lamps had been charged with an atmosphere of illuminating gas, naphtha, and other hydrocarbon vapors, both at atmospheric pressure and under partial exhaustion, with a view to arresting consumption of the carbon pencil. It was found that the globe soon blackened, and this to an extent commensurate with the amount of the confined gas or vapor, while the carbon pencil became of a bright gray color, but otherwise suffered no change. It thus appeared that the deposit which blackened the globe could not have proceeded from the pencil; and investigation showed that the hydrocarbon atmosphere had been decomposed, the hydrogen set free, and the carbon deposited; and inferentially it appeared that the gray color of the pencil was due to the mechanical combination with it of a portion of the dissociated carbon.

By easy advances the conclusions were reached that if there was any deposit upon the pencil from any given volume of gas, there would be a greater deposit from a greater volume of gas; and that the greater the heat developed in the pencil, and the slower the deposition, the more dense and perfect would be the carbon. These conclusions were subsequently verified. It was found that in a stream of hydrocarbon gas or vapor an imperfect pencil of carbon was rendered perfect, the original points of imperfection, being of proportionately high resistance and heating proportionately to a higher degree than the perfect portions, receiving a deposit which compensated for such imperfection. Thus pencils of carbon of any desired diameter up to one-eighth of an inch, and of a density and homogeneity before unthought-of, and capable of taking a polish like jet, were formed of and upon a mere filamentary conductor. The original filament appeared to be unchanged, the deposit carbon being in the form of a cylinder surrounding it and possible to be broken off from it.

It was found also that the pencil could be as veritably welded or joined to the connecting carbon blocks as two pieces of metal are welded or joined together, and the Sawyer-Man carbon horseshoe, which was perfected and exhibited in the winter of 1878–9, was treated by this process, the ends of the horseshoe being welded to the supporting blocks in order to secure perfect electrical contact.

From obtaining a cylindrical deposit of carbon upon a filament of ordinary carbon, the manufacture of pencils entirely of deposit carbon was attempted. The cylinder was sawed through lengthwise by means of a rapidly-revolving, smooth, thin disk of steel, and the original filament removed. The two portions, semicylindrical in shape, remaining, were then subjected to treatment. The most perfect of all these carbons were prepared by taking sticks of fine willow charcoal, and first saturating the same with syrup and subjecting to heat as in the Carré process, in order to increase their conductivity. The sticks were then divided into pieces one-half an inch in length and three sixty-fourths of an inch in diameter, and placed between carbon-holders for treatment. Heated to extreme incandescence and surrounded by an atmosphere of hydrocarbon, the deposit described immediately formed. The pencil, with shining, rounded ends, was then filed on one side until the original willow was exposed, but leaving the ends of the pencil untouched. The willow being next removed, a pencil of boat shape and remarkable durability was obtained. The Sawyer-Man lamps, as exhibited in New York, were all furnished with carbons of this character, and to the perfection of these boat-shaped, electrically-formed carbons was due their comparative success. To the necessity of frequent renewal, and the time and skill required to produce the carbons, was due the commercial failure of these lamps.

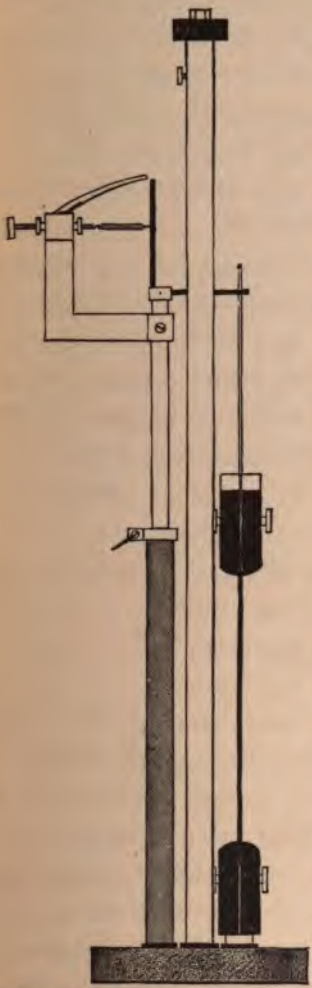
Fig. 41. Carbon-Treating Apparatus.

In preparing long pencils of carbon, allowance must be made for the expansion of the original filament. The Sawyer depositing apparatus (Fig. 41), which holds the filament, is entirely immersed in a hydrocarbon bath. The decomposing current, entering by way of the metallic uprights fixed to a soapstone base, passes through the filament by way of its carbon-clamps. The upper clamp, balanced on a knife-edge, is removable. In this, when removed, one end of the filament is secured and the clamp is then put in position. Next the lower end of the filament is swung between the jaws of the lower fixed clamp, and, this having been tightened, the cam-lever above is thrown up, and the filament thus placed under tension. When the current is applied there ensues violent ebullition of the liquid composing the bath, due to the rapid disengagement of hydrogen; dense volumes of smoke arise, and in from fifteen to thirty seconds the filament is covered with a shell of deposit carbon from one sixty-fourth to one thirty-second of an inch in thickness. Olive-oil is the best hydrocarbon for this treatment. Next in order of efficiency, among common hydrocarbons, are the following:

Refined sperm oil;
Absolute alcohol;
Naphtha and gasoline;
Turpentine.

In using the last-named hydrocarbons, great care must be taken not to overheat the bath, and to see that the filament is wholly immersed before applying the current, otherwise there is danger of fire and explosion.

The carbonizing of live willow twigs, with a view to obtaining a suitable bent carbon, by Sawyer & Man, and the carbonizing of paper and bamboo by Edison, substantially close the account of incandescent carbons. Recently, an attempt to better the texture of the filament has been made by Mr. J. W. Swan, of Newcastle-on-Tyne, who forms it from cotton thread, which is subjected, previous to carbonization, to the action of sulphuric acid in order "to produce the same kind of effect of semi-solution and the welding together of the cellulose fibre as is produced in making vegetable parchment from bibulous paper."

The behavior of carbon at different temperatures is strikingly similar to the behavior of glass at proportionate temperatures, similar results in the latter, however, being attained at much lower temperatures than in the former. As examples the following facts are cited: In hardness and brittleness, glass and homogeneous carbon at ordinary temperatures are substantially alike. Glass, drawn into fine threads, and carbon in filaments, may be bent, and to a certain extent twisted, without breaking. Glass and carbon, heated and twisted or bent, retain the changed form and their normal strength at the point of twisting or bending, upon cooling. Glass moderately heated, and carbon intensely heated, if given a blow, fly into fragments.

Glass and carbon are better conductors of electricity when intensely heated than when at ordinary temperatures.

A ten-inch pencil of carbon, heated to extreme incandescence, expands, under slight tension, to a length of 10¼ inches. Upon cooling it does not return to its original dimensions, but only slightly contracts.

# CHAPTER VI.

## NEW FORMS OF LAMPS.

IT was in 1875, after some desultory work, that we first took an active interest in the subject of incandescent lighting. Subsequent years devoted to the perfection of apparatus in connection therewith have greatly augmented the stock of knowledge originally possessed. The theories upon which experimentalists had labored, and the probable causes of their failures, were given careful consideration, and in all matters of doubt the results of practical experiment were made the basis of conclusions.

It did not at first appear that when a carbon conductor is excluded from contact with combining matter, it is nevertheless, in the sense of changing form, destructible; otherwise speaking, the destructibility of all matter subjected to constant and varying tension did not primarily present itself with the convincing force that is born of experience. Many experimenters in incandescent lighting had failed because they had overlooked the fact that nothing is indestructible, or undisintegratable, or unchangeable. Additionally, the Starr-King lamp had failed because there was present in the Toricellian vacuum the vapor of quicksilver, due to heat, with which the carbon entered into chemical combination. Lodyghine obviated an imperfect contact with the carbon conductor by making the luminous section a reduced portion of a large carbon. Lodyguine, Konn, Kosloff, and Bouliguine, recognizing the destructibility of the conductor, sought compensation in self-renewing devices; but their lamps were imperfect in that they did not preserve the carbon from contact with gases with which, at high temperatures, it enters into chemical combination. All of the old lamps, excepting that of Starr-King, were inadequately sealed. All were somewhere attended by conditions calculated to prevent the realizations sought.

To preserve incandescent carbon from chemical change, it must be hermetically sealed in vacuo, or in a globe containing a pure and perfectly dry cyanogen, nitrogen, hydrogen, or hydrocarbon atmosphere. If there is a trace of oxygen or other gas or vapor present, or any third non-gaseous body in condition to come in contact with the carbon, chemical change is the result. Nor can the incandescent carbon establish connection with any metal, for the reason that the carbide of that metal is then formed. Its connections must be with carbon of greater mass, in order that the temperature of the metal contacts may be low and the contacts perfect; and it must itself be pure and also homogeneous, as imperfections in its structure produce consequent points of resistance at which the current concentrates and where disintegration occurs. In the dioxide of carbon (carbonic acid gas), which instantly extinguishes ordinary flame, the incandescent conductor is consumed, not quite so rapidly, but just as surely, as in air. In the monoxide of carbon consumption is certain, though still less rapid. The explanation of this is found in the fact that a current of the heated atmosphere is constantly flowing past the conductor, and the heat of the conductor is so great that the carbonic oxide is decomposed before the two come in contact; and the oxygen thus set free, and having a higher affinity for the carbon of the conductor than for the less heated atom from which it has been dissociated, combines with the former, while the dissociated carbon atom is deposited either upon the interior works of the lamp or upon the inner surface of the enclosing globe; or the oxygen rises in a free state (the carbon being deposited as described), and upon subsequently coming in contact with the incandescent conductor thereupon combines with it to form the monoxide. The monoxide, not the dioxide, is always formed when there is a limited amount of oxygen present. Thus it will be clear that, however slight may be the trace of oxygen in the sealed globe of an electric lamp, and however great in mass the incandescent carbon may be, it is only a question of time when this circular process of chemical dissociation and recombination will entirely destroy the conductor and deposit it upon the interior works and the globe of the lamp. What occurs with oxygen occurs with other substances having an affinity for carbon at high temperatures; and to procure a non-combining atmosphere sufficiently free from impurities involves a very delicate laboratory process. The employment of hydrogen is disadvantageous in these respects, that it necessitates a more powerful current to produce a given light than when the conductor is in vacuo or surrounded by nitrogen, and that, should any leak occur, air sufficient to form a dangerous explosive mixture soon finds access to the globe. For the latter reason an hydrocarbon atmosphere is impracticable, in addition to the fact that the decomposition of the hydrocarbon so blackens the globe as to greatly obscure the light. The incandescent carbon, therefore, can only be practically employed in vacuo, or surrounded by an atmosphere of pure nitrogen, or in a partial or nearly perfect vacuum of hydrogen, nitrogen, cyanogen, or hydrocarbon gas, which last, however, speedily becomes a vacuum of hydrogen, for the reason that the hydrocarbon is decomposed and the hydrogen set free in the lamp.

The idea of protecting carbon from chemical change by enclosing it in a vacuum or a carbon-preservative atmosphere is, as has been shown, by no means new. Atmospheres of nitrogen, hydrogen, and the carbonic oxides, and their vacuums, as well as the ordinary vacuum, have been employed in the laboratory for many years, and are common property of which all experimentalists may avail themselves.*

Next to preserving the carbon from chemical change, the greatest difficulty is found in hermetically sealing the globe of the lamp. The sealing of glass upon platinum is familiarly shown in Geissler vacuo-tubes; and while the degree of skill required for this method of

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* The following data, abstracted from the report of Colonel Bolton to the London Society of Telegraph Engineers, March 26, 1879, refer to expired English patents relating to incandescent lighting:

1841. De Moleyns, 9,053. Uses a coil of platinum wire at the base of which is a piece of spongy platinum and into which falls a shower of finely-pulverized boxwood charcoal or plumbago, the whole being enclosed in an exhausted tube.

1845. King, 10,919. Application of continuous metallic and carbon con-sealing is rare, the Geissler method is undoubtedly as perfect as any yet devised.

In the Edison lamp (Fig. 42) the Geissler method of sealing is employed, the two conductors, A A, leading to the carbon loop, D, being sealed at B B in the glass of the compound globe, E. In order to obtain a perfect connection with the carbon filament its ends are enlarged and clamped in suitable blocks, C. Exhaustion of the air by way of the neck, F, to the one millionth of an atmosphere, leaving in the lamp a portion of oxygen represented by $\frac{1}{5000000}$, follows. The filament originally used by Mr. Edison was prepared by cutting card-board into the desired shape, and carbonizing the same by placing the loops thus formed in layers within an iron box, with intervening layers of tissue-paper, closing the box to exclude oxygen, and raising the whole to red heat in a furnace. Lack of homogeneity in the structure of these carbons subsequently led Mr. Edison to the adoption of carbonized bamboo-wood, which is worked down by successive cutting and scraping until the entire length of the loop between its enlarged ends, which length varies from five to seven inches, is reduced to a uniform cross-section of from one

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ductors, intensely heated by the passage of a suitably regulated current of electricity. Uses Toricellian vacuum when carbon is employed. [King was Starr's agent.]

1848. STAITE, 12,212. Uses an iridium or an iridio-platinum wire.

1850. SHEPARD, 13,302. In a ground-glass globe, exhausted, a vertical rod of carbon is, by means of a weight, pushed down into a small carbon cone constituting the terminal.

1852. ROBERTS, 14,198. Complete apparatus for rendering a rod of graphite, coke, or charcoal incandescent in a non-combustible atmosphere. Placing the carbon in a deoxygenated atmosphere (as hydrogen or nitrogen), rarefied, was patented by Staite in 1846, No. 11,499.

sixty-fourth to one thirty-second of an inch. The delicacy of manipulation of the wood, in order to make the filament uniform in size throughout, renders its cost excessive; but this difficulty, in a measure at least, will probably be overcome. The resistance of the loop when carbonized is from 100 to 300 ohms, and the amount of light obtainable, with safety to the conductor, varies from two to ten candles. Fig. 43 is an illustration of an Edison bamboo filament, full size, before bending and carbonization.

In carrying out the Edison method of manufacture a glass bulb (Fig. 44), of the size desired for the enclosing globe of the lamp, is formed, with a supporting neck, extending in one direction, of a diameter sufficient to permit the passage of the illuminating conductor through it. Preferably a piece of tubing, of the size of the neck, has the bulb blown in it. Upon a point on the bulb op-

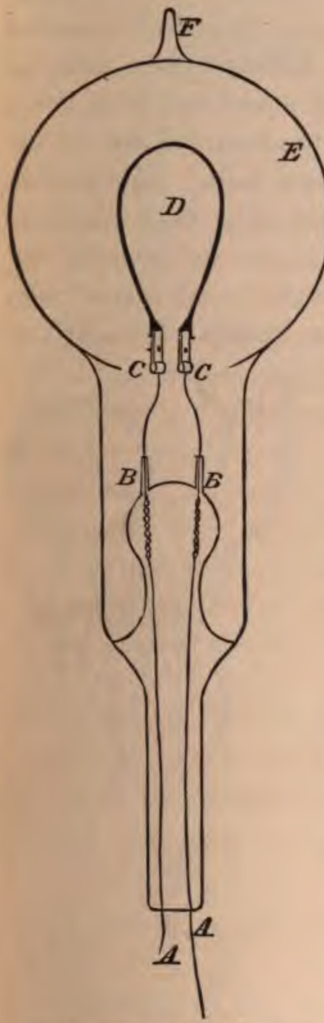

Fig. 42. The Edison Lamp.

posite the centre of the neck is formed a long tube for attachment of the bulb to the air-exhausting apparatus. Upon the end of a smaller piece of tubing a small bulb is formed, and the body of the tube, a little below the bulb, is enlarged for a small space to about the size of the supporting neck of the first bulb. This portion constitutes the loop-supporting part, platinum wires, terminating in clamps for holding the loop, being passed through it and hermetically sealed therein. After the filament is in place, as

Fig. 43. Bamboo Filament.

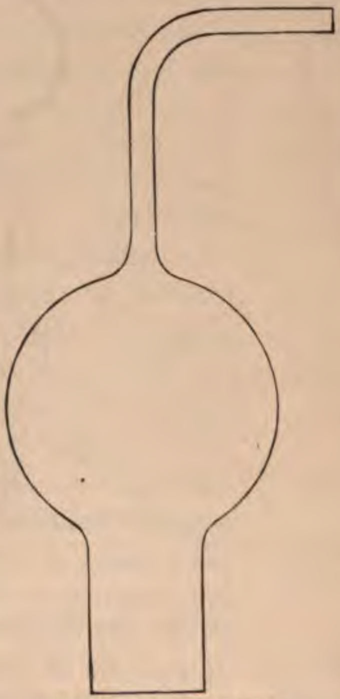

Fig. 44. Edison Outer Globe.

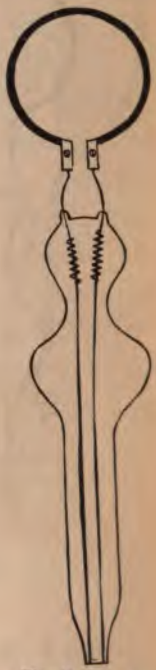

Fig. 45. Inner Globe and Works.

shown in Fig. 45, the small tube is passed up into the bulb of the large tube until its further passage is stopped by the neck of the latter, when the two are sealed together by fusion, and appear as shown in Fig. 46.

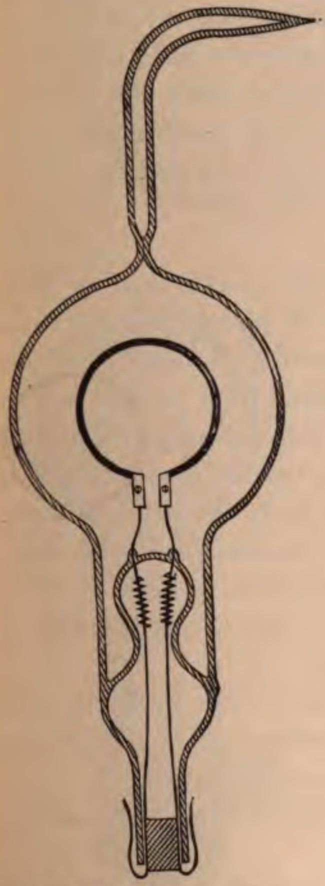

Fig. 46. Globes joined together.

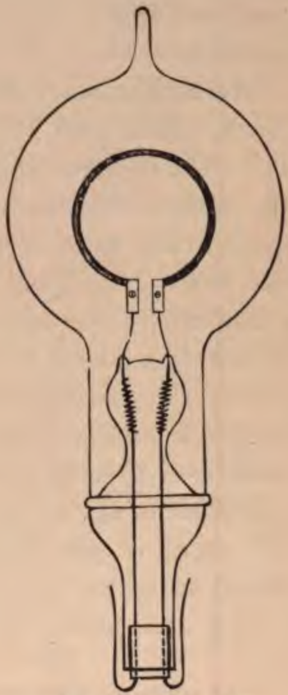

Fig. 47. Lamp Sealed.

The mechanical construction of the lamp being now complete, it is attached to the vacuum-pump by the neck before-mentioned, and when a proper degree of exhaustion has been attained, the end of the tube is softened and sealed by heat, after which the lamp is removed from the pump. Finally, the tube is softened and sealed near its point of juncture with the globe, when the portion remaining above is broken off and the neck again softened and sealed immediately above the sealing before made at the point of juncture. Fig. 47 shows the completed lamp.

The Maxim lamp (Fig. 48), recently exhibited in New York, differs from Mr. Edison's in no essential particular. The Geissler method of sealing is employed, and the carbon filament, manufactured from card-board, is made in the form of a double loop, closely resembling the letter M. Thus prepared, the light obtainable is substantially the same as that from the Edison lamp. When the filament is treated by immersion in hydrocarbon by the process of depositing already described, its section is enlarged and improved, and the light then obtainable is from 10 to 30 candles.

Before sealing his lamp, Mr. Maxim fills the globe with the vapor of gasoline, to the exclusion of all air, and finally exhausts by means of the vacuum-pump.*

Run at a power of eight candles, in a nearly perfect vacuum, the life-time of filamentary carbons is from ten to one hundred hours.

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* An erroneous impression, in regard to the Maxim lamp, due to the employment of gasoline in the process of exhaustion, is that it is a self-renewing device—*i.e.*, that whenever consumption or disintegration occurs, the filament is repaired by an ever present supply of hydrocarbon. The reverse is the case. When ready for use the globe contains a trace of gasoline vapor, and this is almost immediately decomposed, setting the hydrogen free, and leaving present a trace of hydrogen merely.

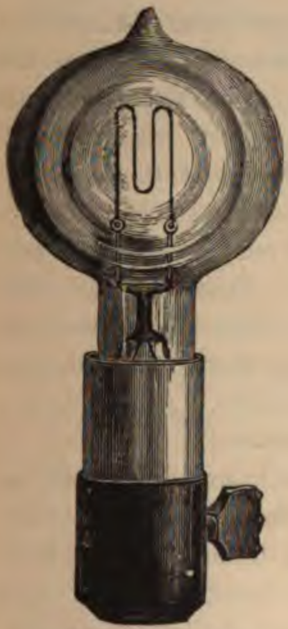

Fig. 48. The Maxim Lamp.

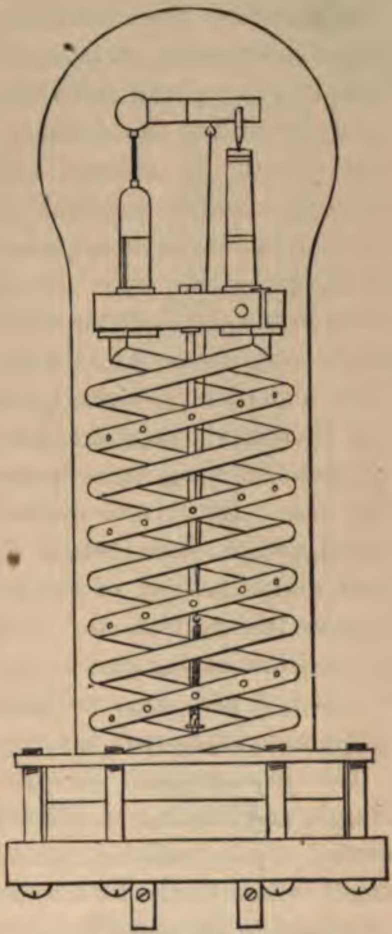

Fig. 49. The Sawyer-Man Lamp.

The Sawyer-Man system of lighting was exhibited in New York in 1878. Fig. 49 is an illustration of the first device of these experimentalists to which publicity was given.

In this lamp the enclosing globe was provided with a flange constituting an integral part of the globe, and a disk of glass perforated with two small holes was accurately ground to fit the same. The ground surfaces were coated with fir balsam, and the globe and stopper strongly clamped together by means of bolts passing through an elastic flange below the stopper, and a metallic flange bearing upon the glass flange. Through the holes in the stopper passed the diminished ends of two stop-cocks, whose joints were made perfect by drawing their shoulders powerfully down upon paper washers first thoroughly impregnated with balsam. Subsequently, melted sealing-wax was poured around the whole of the base. By this means very perfect joints were secured, and to retain them so it was only necessary to prevent undue heating of the parts. Therefore, the conductors leading from the outside stop-cock connections to the illuminating part of the lamp were given considerable length and large radiating surface. An insulating diaphragm supported the upper works.

The incandescent carbon pencil, one-half inch in length, and varying in different lamps from one thirty-second to one-twelfth of an inch in diameter, was held in small carbon blocks let into larger blocks, one of which was fixed in the lower standard, and the other in a connecting arm, which, in order to allow for expansion and contraction of the pencil without friction, was supported upon a knife-edge bearing. This connecting-arm was held in place by a coiled spring. The spiral conductors consisted of tubes, one of which was provided with openings along its length, and each connecting with a stop-cock. A lump of metallic sodium or potassium as an absorbent of oxygen; and its oxide, when formed, as an absorbent of carbonic acid gas, was placed in the lamp. To charge the lamp, a stream of nitrogen was caused to flow through one of the tubes to the upper part of the globe, escaping by way of the openings in the other tube. Carbons of a

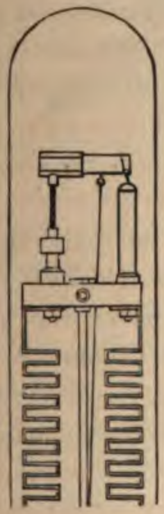

Fig. 50. Lamp with fluted Conductors.

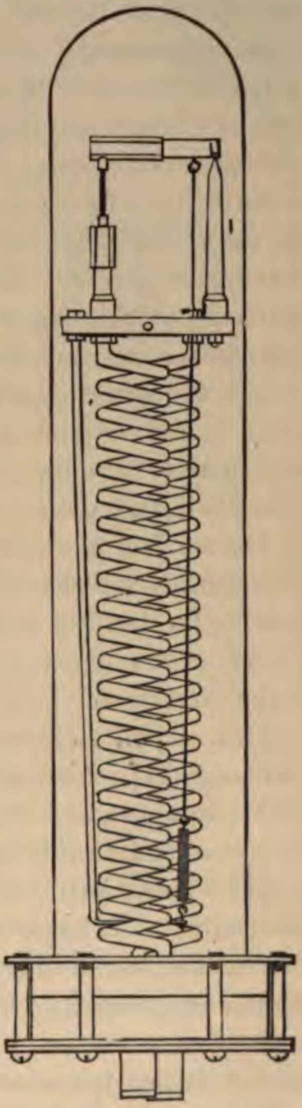

Fig. 51. Perfected Lamp.

density before unattained were employed in this lamp; and although, through imperfect contacts and a faulty atmosphere, many of the lamps failed to last more than a few hours, some of them were used daily for several weeks without exhibiting marked change. In the construction of the lamp, it was found essential to round the ends of the carbon pencil, and to make a tapering cavity in the small connecting-blocks, which were firmly set in the larger blocks. The final sealing of the lamp was effected by soldering the stop-cocks. Fig. 50 represents the lamp in another form, with radiators of copper ribbon to prevent conduction of heat to the base; and in Fig. 51 is shown the perfected lamp, with small spiral conductors, in which the soap-stone was replaced by a metallic diaphragm.

The Sawyer-Man experiments were of an extensive and diversified character, and among the earliest attempts to obtain a practicable lamp was the including of an arch or loop of carbon in the circuit of the radiators (Fig. 52).

This carbon loop was originally employed in March, 1878, a rod of retort-carbon being turned true in a lathe and bored out to form a tube; from this, thin flanges were cut, and after being clamped between carbon washers, the upper half was left standing and the lower part broken out. It was not until the following winter that the carbonizing of different substances in the form of a loop, and especially twigs of fine willow, was attempted, with varying results. A year later Mr. Edison greatly improved the manufacture of these loops by processes much better calculated to attain the end desired than those employed by Sawyer & Man, whose success in this direction was limited.

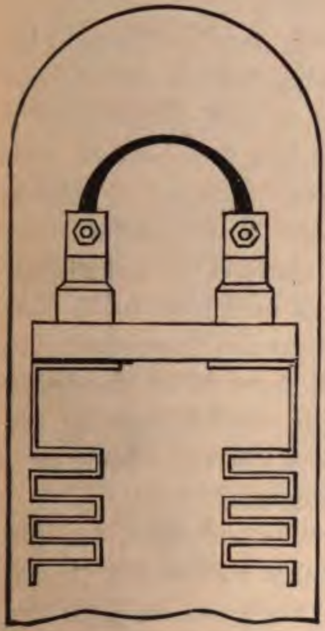

Fig. 52. The Horseshoe Lamp.

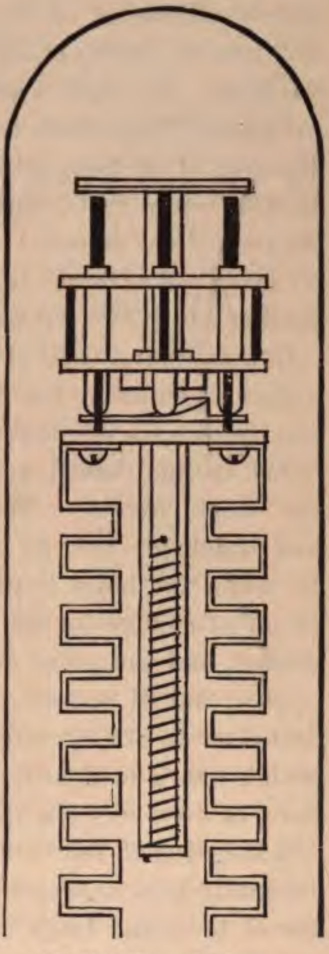

Fig. 53. Self-renewing Lamp.

The fact appearing that it is only a question of a brief period of time when a carbon loop or pencil subjected to the action of powerful currents will suffer disintegration, it is clear that some means of renewing the incandescent conductor of any lamp must be provided; and this renewal must be accomplished without destroying the lamp. To replace a Sawyer-Man carbon required a workman's time from two to three hours, and the recharging of the lamp with absolutely pure nitrogen cost about seventy cents, without taking into consideration the cost of the carbon. It was therefore an impracticable lamp. To obviate frequent renewal the first Sawyer feeding-lamp (Fig. 53) was devised.

In this lamp several short carbon pencils were held by copper rods, as in the Konn lamp, and as fast as one was consumed or disintegrated, a cam, rotated by a coiled spring, forced another carbon into contact with the block above. Thus a very durable apparatus was obtained, but by no means a successful one; for when the lamp is properly charged, or exhausted, chemical change in the carbon is no longer to be considered, and the point of disintegration is generally the upper point of contact. In this form of self-renewing device we do not, therefore, obtain the full value of the pencil, which ordinarily drops out when it is only partially or even very slightly disintegrated.

A long pencil, fed through an elastic contact, was the originally-held conception, and this was eventually resorted to in the lamp (Fig. 54) designed early in the year 1879. In this lamp, by means of an electro-magnetic switch, an electro-magnet, operating through the glass stopper of the globe, was caused to feed upward between elastic contacts, as fast as disintegration occurred, a long carbon pencil travelling in a metallic tube.

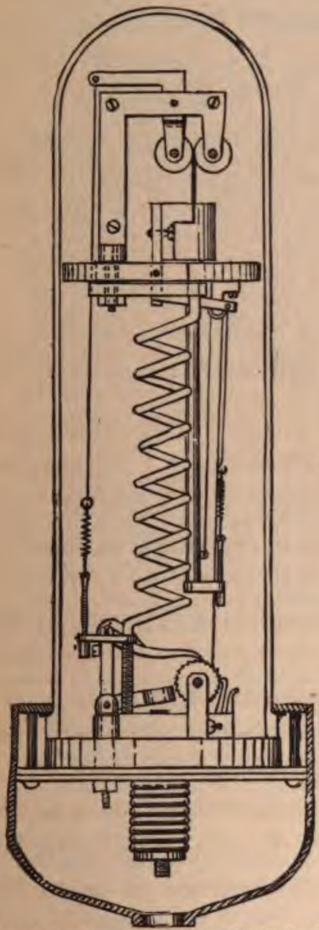

Fig. 54. Electro-Magnetic Self-Renewing Lamp.

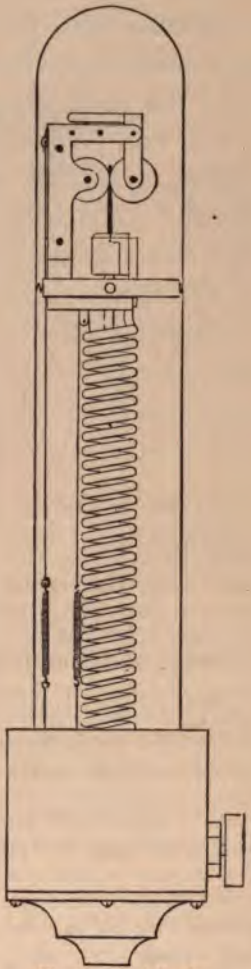

Fig. 55. Hand-Feeder.

Imperfections in the operation of electro-magnetic feeding devices led to the designing of another lamp

(Fig. 55), in which the pencil was fed upward from the outside, when necessary, or drawn downward from its connection with the upper contact-rollers when extinguishment of the light was desired. With lamps of this type the first private residence, it is believed, in the world, was practically illuminated by electricity in the winter of 1879–80 and during the following month of March.* The halls, parlors, and upper chambers of a New York dwelling-house were supplied with electricity, through a single conductor, by a generator located a block and a half distant. Each light was turned on or off, or graduated to any desired degree of intensity, independently of other lights. The internal resistance of each lamp was about .25 ohm.†

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* No. 226 West Fifty-fourth Street, New York City.

† Since this was written our attention has been called to the fact that at Salem, Mass., during the month of July, 1859, Professor Farmer lighted his parlor by two incandescent platinum lamps. In a letter to the Salem *Observer* of November 2, 1878, Professor Farmer adds: "And this electric light was subdivided, too! This was nineteen years ago, and it was undoubtedly the first dwelling-house ever lighted by electricity. A galvanic battery of some three dozen six-gallon jars was placed in the cellar of the house, and it furnished the electric current, which was conveyed by suitable conducting-wires to the mantelpiece of the parlor. Either lamp could be lighted at pleasure, or both at once, by simply turning a little button to the right for a light, to the left for a dark." It is barely possible that Professor Farmer's memory may be in error in respect of dividing the current. Whether it would have been more natural for him to divide the battery into two separate parts of some one and a half dozen jars each, and operate one lamp from each part, than to go to the trouble of arranging resistances and complicated switches in order to operate so small a number of lamps as two from a single battery in close proximity to them, is not considered; but it would have been more satisfactory if, in making the above claim, Professor Farmer had stated in what manner a button was arranged so as to light both lamps at once, or to light either one separately, by the one operation of turning the button to the right.

# CHAPTER VII.

## NEW FORMS OF LAMPS (CONTINUED).

WE may now be supposed to have arrived at an adequate conception of the principles underlying the various forms of incandescent lamps. We have seen that an incandescent carbon, however completely isolated from gases with which at high temperatures it enters into chemical combination, is a destructible mass of matter. We have, perhaps, reached the conclusion that means for its renewal must be provided, and that this renewal must not be frequent, and that it must be cheaply accomplished. The lamp, furthermore, must be cheaply and hermetically sealed, and readily recharged with a carbon-preservative atmosphere, or exhausted of such atmosphere, or exhausted of atmospheric air.

The new Sawyer lamp, exhibited in New York, and at the Franklin Institute in Philadelphia within the past few weeks, is designed to meet the requirements mentioned. The illustration (Fig. 56) shows this lamp in its perfected form.

In Fig. 57 the lamp is shown with the interior works and base apart from the enclosing globe. Upon a thin metallic base is fixed one of the upright metallic conductors leading to the top of the lamp. The other conductor is fixed to an insulated bolt passing downward through the centre of the base. These conductors are of steel, in order to prevent rapid conduction of heat to the base, and are formed as shown in order that they may be readily stamped from sheet-metal and pressed into the required shape. By means of a copper plunger attached to a wire running over a winding-drum at the base of the lamp, in which drum an ordinary watch-spring, furnishing the motive power, is coiled, a long pencil of carbon in the plunger-tube is automatically fed upward through the lower elastic carbon-contacts to a connection with the upper perforated carbon-block. Thus the pencil is constantly forced to a bearing against the upper carbon-block until entirely disintegrated; and when entire disintegration has occurred the plunger closes the circuit of the lamp. As heretofore explained, the point at which disintegration mainly takes place is the upper point of contact; and as, when the pencil is protected from combining matter, this disintegration amounts to between the one-hundredth and the fiftieth part of an inch for every hour the lamp is run, and as the pencil is eight inches in length, it follows that the useful lifetime of the carbon is from 400

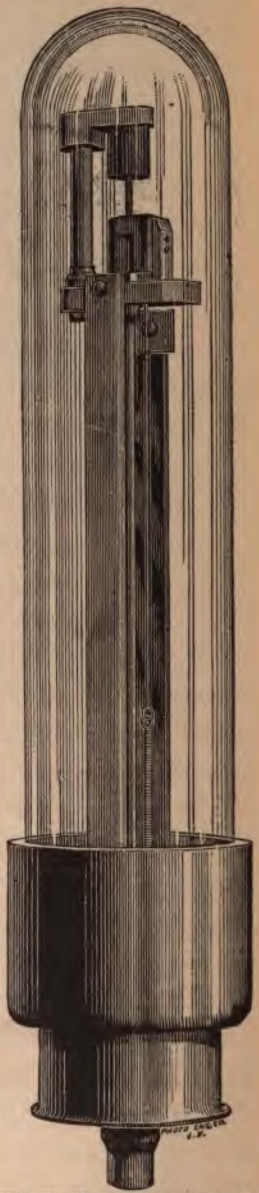

Fig. 56. The Perfected Sawyer Lamp.

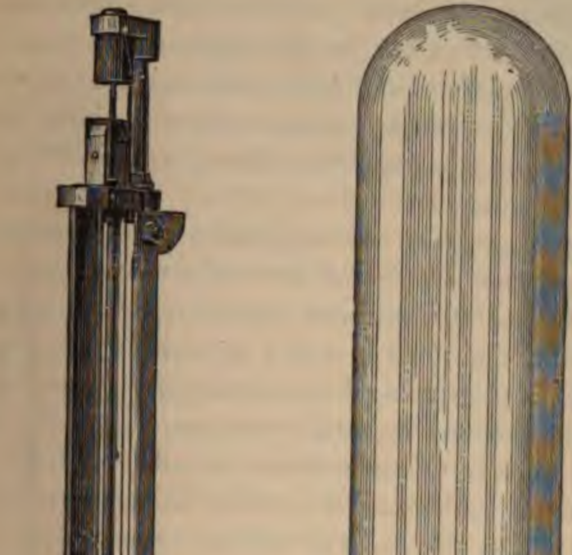
PHOTO-ENG. CO. N.Y.

Fig. 57. The Sawyer Lamp, apart.

to 800 hours, equivalent to four hours' daily use for from 100 to 200 days. In this calculation it is assumed that the intensity of the light shall not exceed that of two good five-foot gas-burners, or at most thirty candle-power. Run at a higher intensity the durability of the pencil is diminished.

The glass globe of the lamp has no direct connection with the base supporting the lamp mechanism. In a thin, spun-metal, open cup, amounting practically to a short tube, the globe is sealed by heating the cup and the glass, and pouring into the annular space between the glass and cup a sealing compound which is elastic at all ordinary temperatures, adheres to both glass and metal, and does not soften at temperatures attained in the lamp. The sealing space is two inches deep and one-quarter inch wide, and the sealing compound substantially as homogeneous as glass; hence the element of leakage at this point may be disregarded.

In order to place the carbon pencil in the lamp, the upper carbon-block is carried to one side by moving the sustaining-arm on the standard connected with the insulated steel upright, and space is made for the pencil by moving the plunger to the bottom of the tube and thus unwinding the wire on the drum. The lower carbon clamping-blocks, whose mutual pressure is sustained by a spiral spring, placed lower down in the lamp so as to prevent its undue heating, are then separated, and the pencil of carbon is dropped into the tube. Finally, the upper carbon-block is moved back into the position shown, when the lower carbon-clamps and the winding-drum are released, and the pencil is brought to a bearing in a central opening through the upper carbon-block. The circuit is by way of an insulated wire enclosed in the bracket to the central insulated bolt, one of the upright steel conductors, and the upper carbon-block; and downward, through the pencil, as far as the lower clamping-blocks, and the other upright steel conductor, to the base of the lamp and the bracket. To connect a lamp in circuit it is therefore necessary to fix it to the ordinary nipple-thread of a gas-fixture, the two contacts thus being established.

The peculiar shaping and general design of the parts of the lamp are such as to facilitate and cheapen their manufacture. The carbon-blocks are formed in moulds. To prevent oxidization from handling and exposure, all of the parts are nickel-plated. All of the metallic parts above the upright steel conductors, and the pencil-tube, are of pure copper. The leading wires of the winding-drum and the coiled clamping-spring are of steel. All of the parts at the base of the lamp, excepting the screws, are of brass. A stop-cock, or a single opening, through the base, closed by a short brass screw, is employed in the charging of the lamp.

When the carbon pencil has been introduced, the glass globe, sealed in the brass spun cup, is lowered over the works and fits closely to the shoulder turned on the base. The workman then passes a soldering-tool around the junction of the cup with the base, and this joint is hermetically sealed. To facilitate the soldering, as well as to economize material and prevent excessive heating of the sealing compound between the globe and the cup, the base as well as the cup is made only thick enough to be substantial. To renew the pencil, when entirely destroyed, the junction of the cup and base is rotated in the flame of a Bunsen burner, when the solder softens and the globe and cup are removed. To replace the pencil, and resolder the connection of the cup and base, is the work of a few minutes. The globe, once sealed in the cup, is not again disturbed. At each renewal of the carbon it is of course necessary to refill the globe with nitrogen, the stop-cock or screw, closing the charging opening, being also finally soldered, in order to ensure hermetical sealing of the lamp throughout.

All insulations above the base are of mica, in order that the heat of the upper works may not disengage dust or vapors, whose action upon the incandescent pencil would be deleterious. The diameter of the globe is 2 inches and its length 10 inches. Lamps have been constructed of all sizes down to one having a globe ½ inch in diameter and 2½ inches in length, but the dimensions adopted have been found to be the best in practice. The shape or design of the globe is inconsequential, which may also be said of the general structure of the lamp, except in so far as questions of economy are concerned.

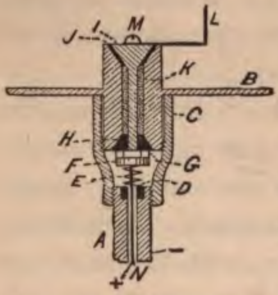

Fig. 58. Bracket-Connections.

The method of sealing the insulated central bolt, and establishing the external connections of the lamp, is shown in Fig. 58, in which A is the arm of any gas-fixture, and B the base of the lamp. The upright conductor L is fastened to the bolt I by a screw, M. In a conical cavity leading to the long bolt-hole is placed a conical fibre washer, J. In passing through this hole the bolt does not touch its sides, but while the base is hot the annular space around the bolt is filled with the same cement, K, as is employed in sealing the globe to its cup, and the nut G, bearing upon the conical fibre washer H, is firmly screwed upon the lower end of the bolt. The cap C is then screwed on to the projection from the base. In a cavity in the end of the bracket is sunk an insulating washer, D, through which passes the insulated

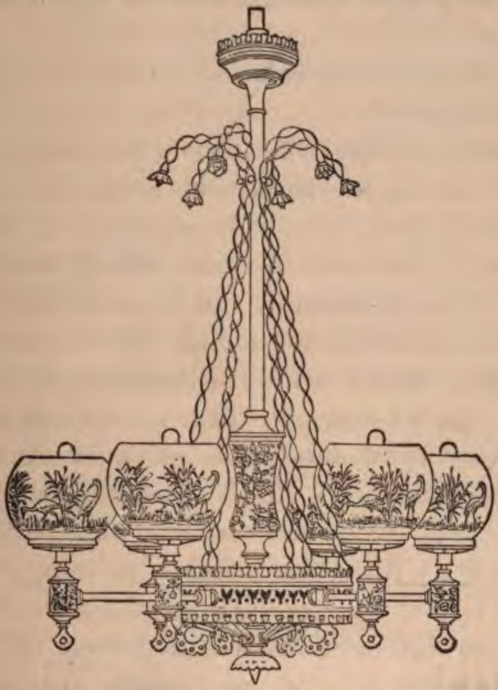

Fig. 59. Chandelier of Lamps.

wire N, screwed into contact-nut F. The coiled spring E gives elasticity to the lower point of contact, so that the lamp may be turned into any position. The long, narrow, annular space around the bolt I, filled with homogeneous cement adhering perfectly to the metal, ensures the hermetical sealing of this last and most difficult joint to seal.

In Fig. 59 the arrangement of a chandelier system of lamps is illustrated.

The luminous intensity of the new Sawyer lamp, which is the same, under like circumstances, as that of all the Sawyer-Man, Konn, Kosloff, Bouliguine, and other Sawyer lamps, is from two to three ordinary five-foot gas-burners. What is meant by this is the intensity of light produced at which it is considered safe to run the lamp continuously, when it is desired that renewal of the carbon pencil shall not be necessary more frequently than once in from six months to a year. Doing two hundred hours' actual work the lamp may be run at an intensity of from 100 to 200 candles. Doing fifty hours' work it may be run at an intensity of from 200 to 600 candles.

Numerous measurements of the power of the light have been made, but the most critical, conducted by Mr. Edgerton, with a Sugg photometer, accord the small-power lamp a luminous intensity of 27.4 candles.*

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* The following certificate by Mr. Edgerton, referring to the perfected Sawyer-Man lamp, and which applies as well to all pencil lamps in which a pencil of the same length and cross-section is rendered incandescent, contains some valuable suggestions in view of the candle-power claimed by gas corporations and that shown at their laboratories :

In order to obtain, when desired, greater illuminating power, a larger lamp (Fig. 60) has been devised.

The dimensions of this lamp are 4 × 16 inches, and its luminous intensity is from 100 to 1,000 candles, according to the length of pencil brought to incandescence and the volume of current supplied. At the Franklin Institute, in Philadelphia, on November 9, 1880, a single large lamp served to illuminate the lecture-hall with the brilliancy of mid-day. There is no difference in construction between this lamp and the small lamp, excepting that in the large lamp the upright conductors are made of round steel rods, which is sometimes true of the small lamps. In the large lamp the carbon pencil is 12 inches in length and $\frac{3}{32}$ of an inch in diameter, with an exposed section of $1\frac{1}{4}$ inches; while in the small lamp it is $\frac{1}{16}$ inch in diameter, with an exposed sec-

NEW YORK, November 8, 1878.

The illuminating power of one of the Sawyer-Man lamps, tested by me this day, gave, in comparison with a standard sixteen-candle burner, a power of 1.714 burners, or 27.42 standard sperm candles.

(Signed) H. H. EDGERTON.

In order to compare the light with that afforded by ordinary gas-burners, the different burners in ordinary use, with coal gas, may be rated about as follows, for a rate of five cubic feet per hour consumption:

Ordinary fish-tail, Scotch tip, about 5 candles.
Young America, brass fish-tail, 8 candles.
Gleason, noiseless Argand, 11 candles.
Lava tip (excavated head), 12 to 13 candles.

A very large flame, burning at a rate of 8 or 9 cubic feet, will give a *pro-rata* light of about 15 candles for 5 cubic feet.

The above is based upon gas made from ordinary Pittsburgh coal. Mixtures of cannel or naphtha improve the quality according to the amount used. (Signed) H. H. EDGERTON.

London is supplied with gas of 16 candle-power per 5-foot burner. The Liverpool street-lamps give a light at the rate of 16 candles per 5 cubic feet with 4 cubic feet consumption.

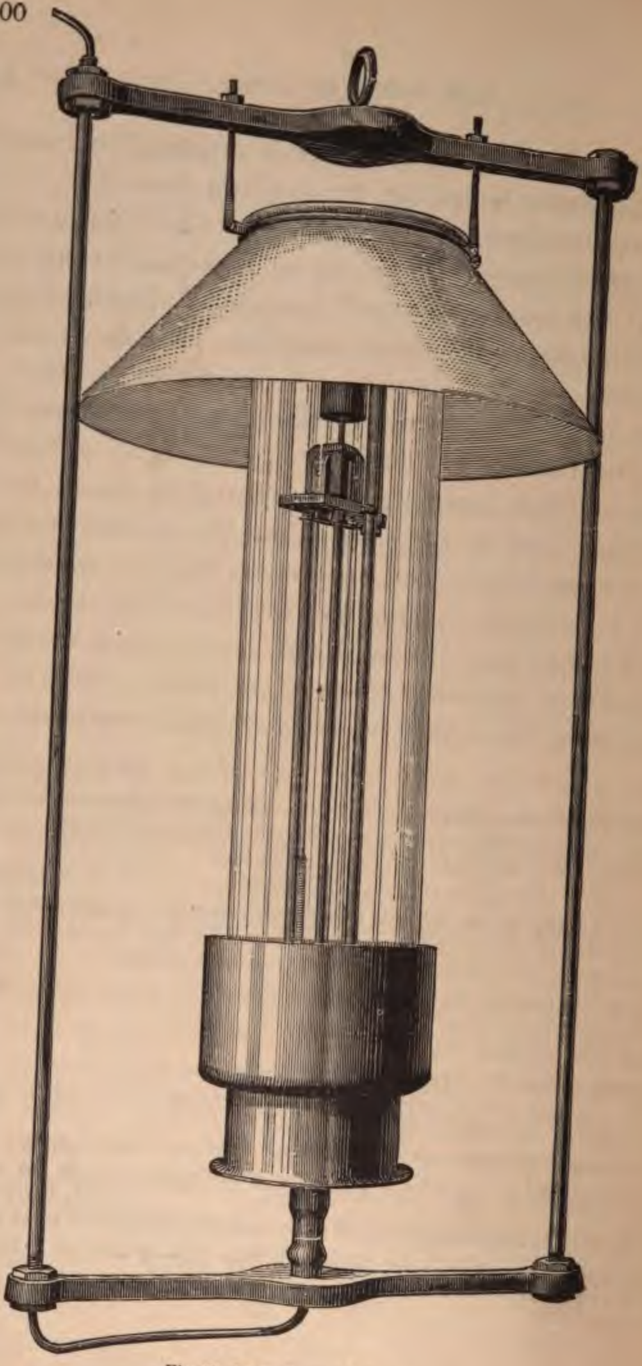

Fig. 60. Large Sawyer Lamp.

tion of ½ inch. Owing to the greater intensity at which the large lamp is run, the working duration of the pencil, when the globe is perfectly charged with nitrogen, is about 200 hours. The cost of renewal (that of the carbon and nitrogen elements) is largely in excess of the cost of renewal in the small lamps, and varies from 25 to 30 cents per lamp.

The permanent, elastic closing of the Sawyer globe in its metallic containing-cup is the only method yet devised that affords the necessary hermetical sealing, excepting that of Geissler, which is employed by Mr. Edison. Many experimentalists in this line have employed hydraulic joints: Kosloff employed a bath of olive-oil around the joints; Guest and others have employed quicksilver; our own experiments, of a similar character, have been confined to viscous hydrocarbons. But all these devices are inadequate; for while they may truly prevent the entrance of air, in-leakage of the mobile sealing substance itself cannot be prevented, and thus there is introduced into the lamp an element which will either destroy the carbon or so blacken the globe as to obscure the light. Every part of the lamp must be perfectly clean; and, indeed, the delicacy of manipulation necessary in the construction of incandescent lamps cannot be appreciated by any one not familiar with the subject, and who only observes the facility with which the skilled workman performs his duties.

Operating upon the principle of decomposition of hydrocarbon and the deposit of the carbon atom upon an incandescent filament, we have constructed an open-air lamp of a somewhat novel description (Fig. 61).

Upon a brass wheel are mounted six carbon horseshoes, all the negative poles of which are connected together on the wheel, and the positive poles of each opposite pair of which are connected together and to opposite segments of a commutator of six segments. The current is directed by a contact-brush and the framework of the apparatus, and, dividing, passes through the uppermost and lowermost carbons at the same time.

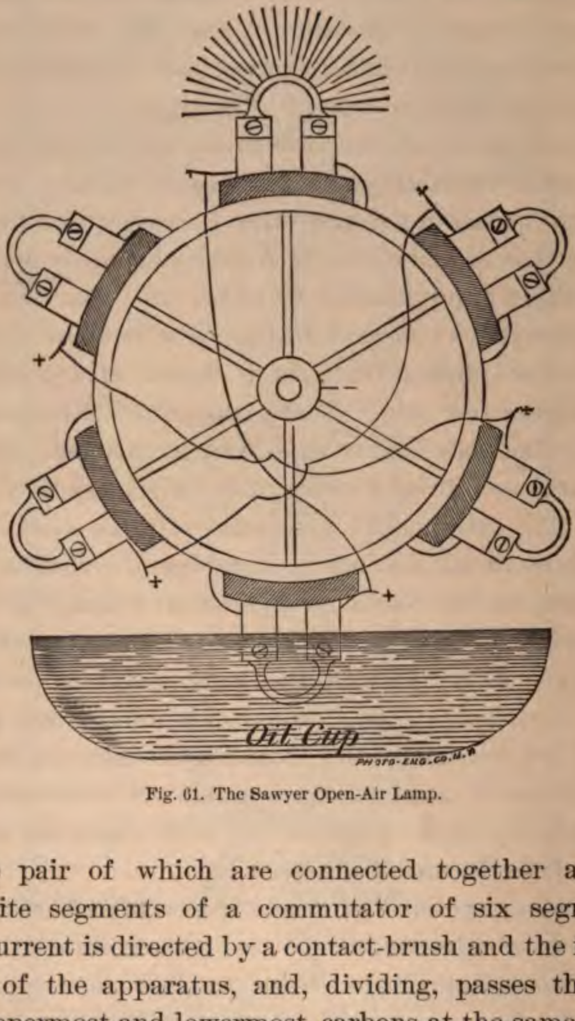

Fig. 61. The Sawyer Open-Air Lamp.

The uppermost carbon burns in the air at intense incandescence, while the lowermost carbon, immersed in oil in a suitable containing vessel, becomes coated with deposit carbon. As the uppermost carbon consumes and decreases in size the intensity of the light does not increase, for the increase in the size of the lowermost carbon balances the effect of the current above by increasing the supply below and decreasing the supply above. By means of intermittently-operating clock-work, before disruption of the uppermost carbon occurs, the next pair of carbons is brought into position ; and the operations described continuing, there is presented the anomaly of an incandescent open-air lamp of indefinite duration, in which, by one operation, light is produced and carbon manufactured, so long as the supply of oil is maintained. The objection to this lamp is that one-half of the current is always employed in renewing wasted carbon.

Light by incandescence is considerably more costly than light by the voltaic arc, when the volume of light obtainable is the sole consideration. The same expenditure of power that will produce a light of 1,000 candles by the voltaic arc will not produce, on the average, more than one-half or one-third as much light by incandescence in a divided circuit. It should not, however, be forgotten that the power of any light decreases as the square of the distance from it, and that one-fourth of the light of the arc distributed at four or five appropriate points, thus reducing the power of each light to one-sixteenth of that of the voltaic arc, will give substantially as good a general illumination as the voltaic arc.

The incandescent light is whatever may be desired. The voltaic-arc light is necessarily a powerful one. The objection to it, if used without a shade, is its great intensity and ghastly effects, and in order to obviate these defects glass shades of more or less opacity are employed, which, according to practical tests, involve a wastage in light of—

With ground glass, 30 per cent.;
With thin opal glass, 40 per cent.;
With thick opal glass, 60 per cent.

In some cases the wastage is nearly, if not quite, 75 per cent.

The loss of light involved in the "toning down" of the arc is clearly set forth in confirmed tests of the power of the Jablochkoff candle, now extensively used in England and France. The actual power of this light is 453 standard candles, but owing to obscuration, occasioned by the opalescent globes with which it is necessary to surround the light, it is found that only 43 per cent. of its full power is available. In incandescent lighting no such loss occurs, and the cost of the carbon consumed, which in voltaic-arc lamps amounts to from four to six cents per hour per 2,000 candles' light, is reduced to an inconsequential figure.

In concluding this chapter, it is proper to remark that the light of an incandescent carbon is very unlike that of the voltaic arc. Its characteristics are the characteristics of daylight; and this is true to such an extent that, from its soft and agreeable nature and absence of glaring effects, the degree of illumination afforded is not always readily appreciated.

# CHAPTER VIII.

## PRESERVATION OF INCANDESCENT CARBONS.

IN isolating the carbon conductor from deleterious gases we have the choice of three distinct processes:

1. Exhausting the globe of air;
2. Filling the globe with nitrogen;
3. Filling the globe with nitrogen, hydrogen, or hydrocarbon gas, and exhausting.

In all cases the interior surface of the globes and the works of the lamp enclosed must be absolutely dry, for the presence of moisture means the presence of the oxide of hydrogen, whose speedy decomposition sets free the destructive oxygen atom. Various methods of artificial drying have been devised, very few of which are serviceable here. The calcium chloride is not only an imperfect drying agent, but has been found to work in some manner injuriously; and the same is true, as to the first part, of concentrated sulphuric acid in its purest form. The degree of dryness necessary is one, in practical operation, beyond the capacity of these chemicals. Anhydrous sulphuric acid is not only dangerous to handle, but injurious to the works of the lamp, and should never be used. The only suitable agent at present known is the phosphoric anhydride, which must be chemically pure and is not imported in this country. We have procured considerable quantities direct from the manufacturers in Germany; as used by Mr. Edison, it is prepared by himself by the combustion of phosphorus in a large containing vessel, to which air is slowly admitted. The resultant vapor is condensed upon the sides of the vessel, which is funnel-shaped at the bottom, and collected in a glass receiver below.

Protracted tests of many kinds of lamps show that in a perfect vacuum as to oxygen, and in an absolutely pure atmosphere of nitrogen, there is no consumption of the carbon, which stands sharp and clear, except as to gradual decay of structure, so long as the volume of current supplied is not too great.

From disintegration, more or less rapid, the carbon cannot be protected. It has been supposed that the entire absence of any atmosphere is more conducive to longevity of the incandescent conductor than the presence of an atmosphere with which it cannot enter into chemical combination, because in the latter case there exists in the lamp a constant circulation of currents of the gas, due to the heat evolved, which may be supposed to "wash" the carbon, and, by some process of reasoning, to waste it away. If carbon, heated to incandescence, usually became a soft, unstable mass, instead of the hard, dense body it is, there might be some foundation for this idea, which perhaps originated from observations of that form of disintegration in which extremely thin, feathery flakes are disengaged and float away. Their disengagement occurs equally in nitrogen and in vacuo, with this difference: that in nitrogen they are carried upward and around by the currents of heated gas, and in vacuo they fall to the base of the lamp.

The preparation of nitrogen sufficiently pure for the purposes of incandescent lighting is ordinarily an extremely delicate laboratory process. Prepared by the burning of phosphorus in a closed air-chamber, it is utterly inadequate; for, however carefully its subsequent manipulations may be conducted, there are present at the outset too many elements of impurity, and a trace of phosphorus always remains.

The best method of obtaining nitrogen that we have employed is that of Prof. Stillman. Solutions of ammonic chloride and potassic nitrite are heated in a glass retort. The vapor-gaseous product, consisting of nitrogen, water, ammonia, and nitric oxide (although the reaction given in the text-books is $KNO_2 + NH_4CL = KCL + N_2 + 2H_2O$), is passed successively through the condenser; sulphuric acid (to remove excess of water), and solutions of iron, caustic potassa, and pyrogallic acid mixed with caustic potassa, in Wolff's bottles; and then through long tubes filled with pumice-stone in pieces, moistened with sulphuric acid. Finally, the gas is passed through tubes containing phosphoric anhydride, and a combustion-tube containing melted sodium, to remove the last trace of oxygen, oxidized particles of which are prevented from coming over by means of Wolff's bottles filled with cotton. The gas is stored in tanks, or in strong iron reservoirs under pressure. Thus prepared the cost of the nitrogen is about ten cents per gallon.

In filling a globe the simplest process is that of "washing out," illustrated in Fig. 62, in which several lamps are connected in series, and a divided circuit. The gas passes from a receiver through a purifier consisting of drying apparatus and a sodium tube, and thence through the lamps F seriatim, the first flow of gas being wasted, and the remainder collected in a second receiver, from which, when filled, it is passed back directly into the first receiver by means of a connecting-tube; and then again passes through the purifier and the lamps. As every gas acts as a vacuum towards every other gas, the lamps become ultimately filled with pure nitrogen. In order to expel occluded air, it is useful to successively heat and cool the carbons while the nitrogen is flowing. By closing and subsequently soldering the stop-cocks, the hermetical sealing of the lamps is effected.

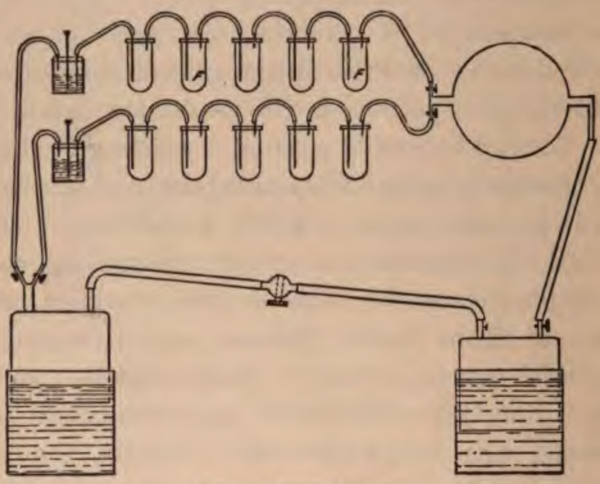

Fig. 62. Nitrogen Process.

Exhaustion of air has been reduced, by means of the Sprengel pump, to a degree heretofore thought unattainable. In the manufacture of the Edison lamp, the method of exhaustion illustrated in Fig. 63 is employed. A is a Sprengel pump, B a drying-tube of phosphoric

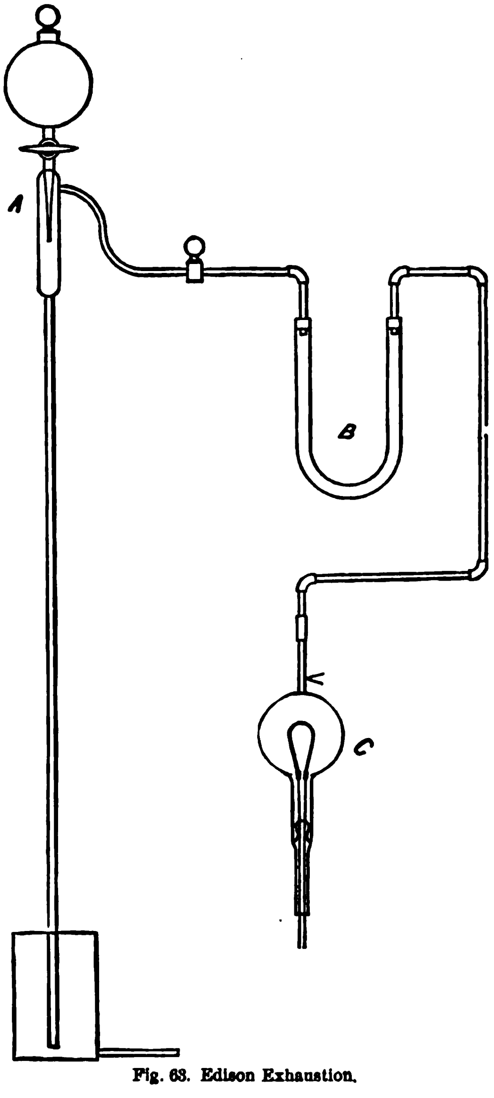

Fig. 63. Edison Exhaustion.

anhydride, and C the lamp to be exhausted. The time required to obtain a nearly perfect vacuum in the lamp is from ten to twenty hours, for the operation of the Sprengel apparatus is extremely slow. The degree of exhaustion ordinarily attained is supposed to be about the one-millionth of an atmosphere.

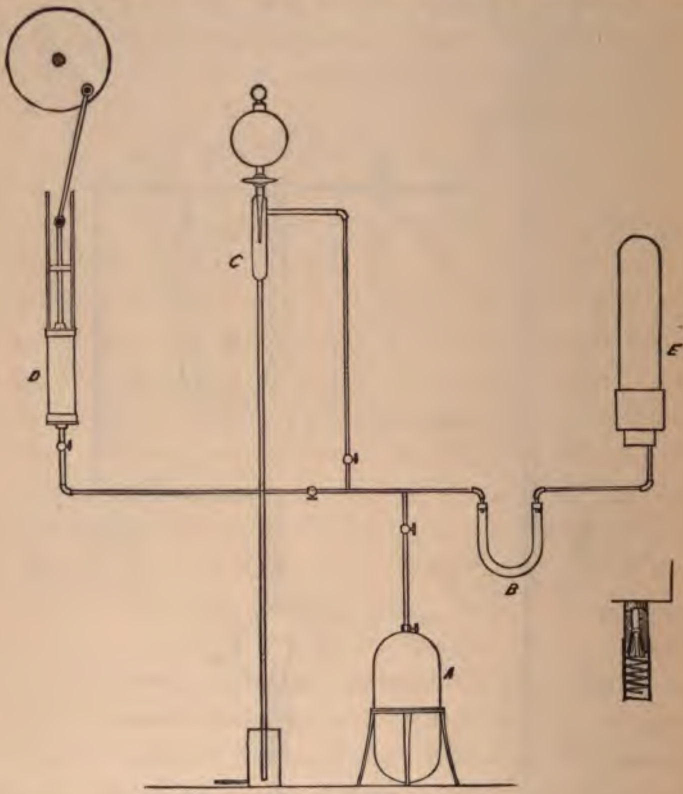

Fig. 64. Sawyer Nitrogen Exhaustion.

In order to improve and facilitate the process of isolating the carbon, the apparatus shown in Fig. 64 is employed in the manufacture of the Sawyer lamp. A is a reservoir of pure nitrogen under pressure; B, the drying-tube of phosphoric anhydride; C, Sprengel pump; D, ordinary air-pump; and E, the lamp or series of lamps to be exhausted. The greater portion of the air is first rapidly removed by means of the machine pump D, when the stop-cock connecting it is closed, and that connecting the Sprengel pump is opened. By this arrangement the slowly-acting Sprengel pump has only a fraction of the whole work to do. As soon as the degree of exhaustion equals the one-hundred-thousandth part of an atmosphere, which is but one-tenth as high as that of the Edison lamp and is quickly accomplished, the exhausting process is stopped, and the reservoir stop-cock being opened, the globe is filled with nitrogen. The reservoir is then shut off, and pumps D and C are used as before, until the vacuum again reaches the one-hundred-thousandth part of an atmosphere. The stop-cock of the lamp, shown in the lower figure, connected by a rubber tube which is prevented from collapsing by an enclosed spiral spring, is then closed by driving in the small tapering pin while the tube is still connected, and subsequently soldering. The proportion of air remaining in the lamp is, therefore, the one-hundred-thousandth part of the one hundred-thousandth part, or the one-ten-billionth part of an atmosphere, a degree of perfection as readily obtained as an exhaustion of .00001 by other means.

Filling and exhausting with hydrogen and hydrocarbon gases operate to similarly reduce the quantity of oxygen present in the lamp, but nitrogen is preferable on account of its greater freedom from impurities. When, however, the hydrogen or the hydrocarbon gas

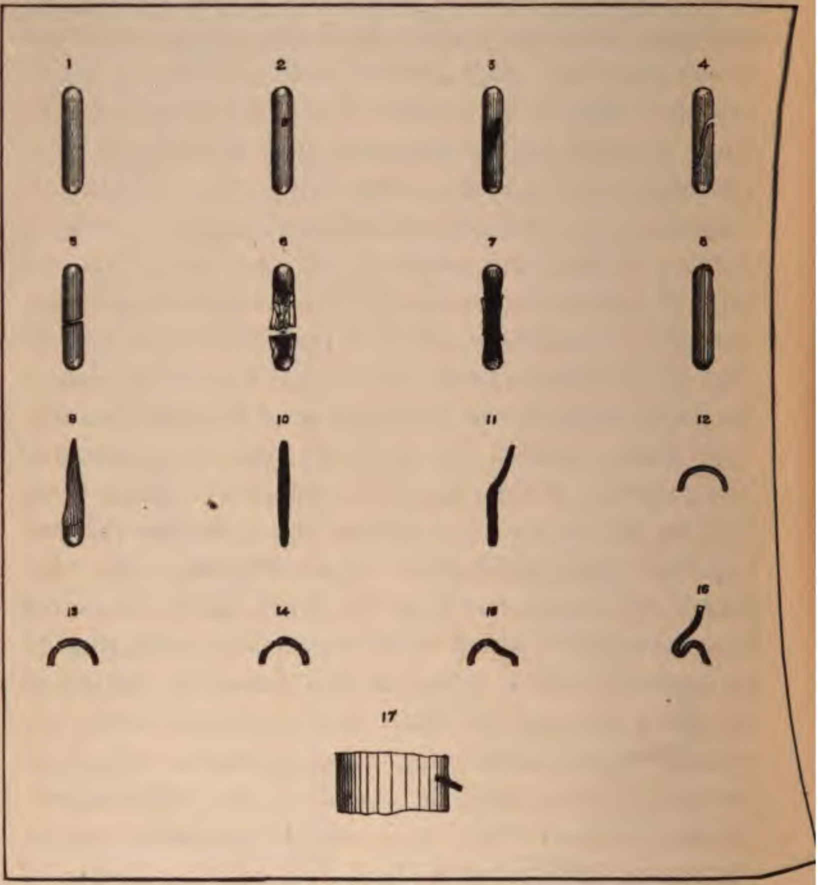

Fig. 65. Carbons.

is absolutely pure, it may be used with equal advantage, and in some cases is perhaps more readily obtainable in the pure state than nitrogen.

In the plate (Fig. 65) the behavior of carbon under varying conditions is shown, but the difficulty of transferring the observations of the eye to the engraver's block necessarily renders their illustration imperfect. In Fig. 1 we have a perfect pencil, sealed in a substantially perfect atmosphere or vacuum.

In the pencil Fig. 2 is shown a cavity forming; elongating, as in Fig. 3; and finally resulting in fracture, as shown in Fig. 4. This occurs in a lamp where combustion is obviated, and would seem to be due to some metallic particle which forms a carbide, slowly extending through the mass of the pencil. In Fig. 5 we have the ordinary rupture, for which there may be any one of several explanations: the presence of an impurity, as already described; a minute crack in the pencil, at which the current concentrates; or possible lateral strain acting upon a point of weakness. The effect attempted to be illustrated in Fig. 6, in which the pencil is literally burst, has been observed but once in our experience, and this was when the dynamo-electric machine was accidentally short-circuited for an instant, accumulating an intense magnetic field, which resulted in a sudden discharge of current of great power upon removal of the cause of the short circuit. The flaking-off of light, feathery-shaped particles of carbon, without combustion, generally from the central and upper part of the pencil, is represented in Fig. 7. Disintegration of the points of contact of the pencil, when it is enclosed in an atmosphere of pure nitrogen, is well illustrated in Fig. 8. In Fig. 9 the pencil is shown slowly consuming, in an atmosphere containing some oxygen, the wastage being greatest at the top and the pencil tapering downward to its full size, due to the difference in temperature of different parts of the pencil. Fig. 10 shows the pencil consuming and diminishing uniformly in section, as in air or a full supply of oxygen, until, if there is any pressure brought to bear, it softens and bends as shown in Fig. 11. Fig. 12 represents a perfect Sawyer-Man loop, and Fig. 13 a loop fractured. In Fig. 14 the loop, diminishing in section at points but otherwise perfect, is well represented. Bending of the loop from heat, as in Fig. 15, occurs only when at different points the carbon is reduced to a mere filament and an arc is upon the point of forming. Long pencils held with connectors, one in each hand, and subjected in the air to extremely powerful currents, have frequently been bent into peculiar shapes, one of which is illustrated in Fig. 16.

In Fig. 17 we have a striking example of the intensity of the heat of an incandescent carbon. Owing to disintegration of the upper point of contact, one of the short Sawyer-Man pencils, losing its support while at limpid incandescence, was projected against the side of the globe, through which it instantly passed as though the glass, which was one-twelfth of an inch in thickness, had been so much tissue-paper, fusing its way slightly downward, and finally settling in the position shown, sealed in the glass as perfectly as a platinum wire is sealed in a Geissler tube.*

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* A section of the globe containing this pencil was, we believe, at one time in the hands of Mr. Hopkins, of the *Scientific American*.

## CHAPTER IX.

### DIVISION OF CURRENT AND LIGHT.

MUCH has been written concerning the loss of light by subdivision of the current, and this has been variously estimated, sometimes as the square and sometimes as the cube of the number of lights among which the current is divided. Upon what data and with what purpose these estimates have been made it is difficult to conceive, for they have no foundation in practical fact.

If to the conducting pipe of a gas system a given volume of illuminating gas is supplied in a given time, and all this gas is consumed in a single burner in order to yield a given light, when we divide the volume of gas thus supplied among two or more burners the total light produced may, indeed, have greatly decreased. We do not, however, supply gas in this manner, but the volume of gas supplied is in direct proportion to the number of burners to be fed.

What is true of gas is equally true of electricity. If a fixed volume of current, sufficient for one light, is furnished to a single lamp the maximum effect is produced, and if we divide this fixed volume among two or more lamps the total effect is greatly diminished; but to suppose that such a division is contemplated is to suppose a similar operation in the case of gas, and criticism of statements based upon such a supposition is, simply, waste of time and labor. When we increase the number of lights in circuit, we increase the volume of current in proportion; and the power of the total light is increased in proportion; and the energy expended in producing the light, and therefore its cost, is increased in proportion.

Without at this time entering into any considerations of the fact that the current from a single generator of electricity has repeatedly been divided between from two to two hundred incandescent burners, the operations of the Brush system of voltaic-arc lighting set at rest the question of economical subdivision.

Two machines of the Brush type are selected for comparison—viz., the six-light and the sixteen-light machines, both of which are in practical use throughout the United States—the light of each of the twenty-two lamps being of the same intensity as that of each and every other lamp.

With the six-light machine the total driving power absorbed per minute is 236,940 foot-pounds, or 39,490 foot-pounds per lamp.

With the sixteen-light machine the total driving power absorbed is 618,090 foot-pounds, or 38,630 foot-pounds per lamp.

It is thus clearly shown that for each lamp added to the circuit there is an expenditure of power in proportion to the additional work, the somewhat diminished power per lamp expended in the sixteen-light machine being mainly due to the element of friction, in which the percentage of absorption of power is less in large than in small generators.

As a matter of fact, there is no limit to the divisibility of the electric current. While the possibility and the impossibility of its divisibility become from time to time the subject of controversial discussion, practical subdivision is a daily concomitant of every telegraphic circuit. Even in telephonic transmission the current generated is divided between the transmitter and the receiving instrument, and in some large telegraphic stations the wires radiate from a single generator in several directions, and in the circuit of each of these wires, at towns and cities along their route, there is placed a greater or less number of instruments, each of which is energized from the source common to all of them; and the proportion of current supplied to each instrument is made substantially the same in all cases by making the resistance of the instruments uniform. The strength of the current thus supplied is, of course, inadequate to the operation of an electric-lighting system, as an ordinary main-line telegraphic battery is inadequate to the operation of even a single voltaic-arc lamp; but if we increase its strength proportionately, and for each telegraphic instrument substitute an electric lamp, we as certainly accomplish subdivision of the electric-light current as subdivision of less powerful currents is accomplished with telegraphic instruments. Indeed, the laws which govern the supply of gas to gas-burners and the supply of electricity to electric burners are daily recognized and availed of in the operation of telegraphic circuits.

For instance, in operating a given number of telegraphic instruments in series, we employ a given number of cells of battery. Suppose, now, that we double the number of instruments and the resistance of the circuit; all the instruments, since they receive proportionately less current, become practically inoperative, and we increase the number of cells, and therefore the electro-motive force of the battery, in proportion to the additional work required, which is that of overcoming the added resistance. If, on the other hand, we divide the current from a single generator among two or more lines, each including a number of instruments in series, we require a current of greater quantity; hence we increase the size of the elements of the generator.

In electric lighting there are five methods of dividing the current from a single generator of electricity:

1. The series system. Passing the current seriatim through the lamps, as in the Brush system of lighting.

2. The multiple system. Connecting the poles of the generator with two parallel wires, and placing each lamp in a branch running from wire to wire, as in the Edison and Maxim systems.

3. The multiple-series system. Connecting the poles of the generator with two parallel wires, and placing a number of lamps in each branch running from wire to wire, as in the Sawyer-Man system.

4. The series-multiple system. Connecting one pole of the generator to a wire which, at the point at which light is needed, divides into a number of strands, each containing a lamp or lamps, and which strands again combine together in a single wire, which runs to the next point of division; and so on indefinitely, returning finally to the other pole of the generator; as in the Sawyer system.

5. The secondary system. Passing the main current

through the primary wire of an induction-coil, in the circuit of the secondary coil of which the lamp is placed (Fig. 66).

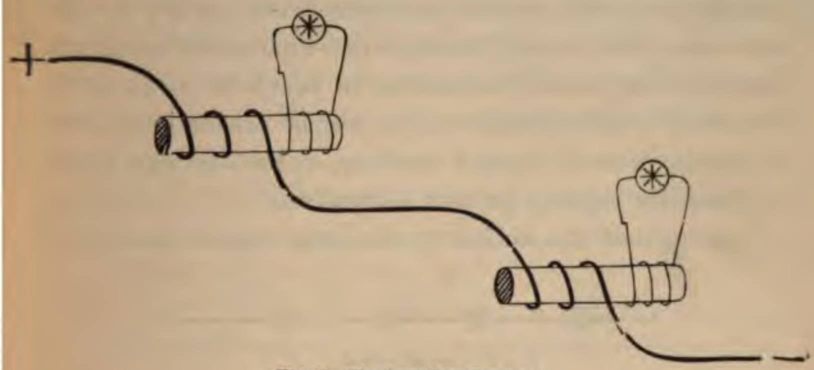

Fig. 66. The Secondary System.

Alternating or intermittent currents are employed, and, owing to the reactive earth inductions, this principle cannot be applied over any considerable territory. Moreover, it involves loss of power in the heating of the iron core of the induction apparatus, is an indirect application of power, and, in electric as in all other forces, direct application is found to be the most economical.*

How to practically divide the current from a single source among a large number of incandescent lamps has been considered a debatable question. We shall content ourselves with glancing at the results which must follow an extension of the four systems which appear to be suitable, assuming that in each case 1,000 lamps and 10,000 lamps are to be operated upon a single circuit. Where there is a limited number of lamps either the series, the multiple, the multiple-series, or the series-multiple systems may be employed with about equal advantage; but where the number of lamps is increased to hundreds or thousands, as must be the case in any general application of electric lighting, considerations novel in character rapidly present themselves.

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* As recently as 1877–78 several claimants to this method of subdivision have appeared, but the system was patented in England by Harrison in 1857 (Letters Patent 588), under the title, "Improvements in obtaining Light by Electricity," and it is not quite clear that Harrison was the original inventor. The Harrison patent expired in 1871, unless the Government taxes were unpaid, in which case it must have expired at an earlier date.

Taking first the series system (Fig. 67), in which the current traverses the lamps seriatim, and assuming that interruption of the circuit of any lamp will not interrupt the entire circuit, we have with 1,000 lamps a resistance, not including the internal resistance of the generator or the external resistance of the main conductor, of 1,000 ohms. With 10,000 lamps the resistance becomes 10,000 ohms.

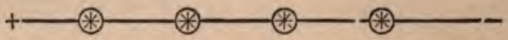

Fig. 67. Lamps in Series.

Can this resistance be overcome by any practicable construction of generator?

The electro-motive force of current necessary to operate an incandescent lamp of one ohm resistance is, as to the lamp, such as will yield a voltaic arc $\frac{1}{32}$ of an inch in length. The electro-motive force necessary to overcome the resistance of 1,000 lamps is, therefore, that which will yield an arc 31¼ inches in length, or with 10,000 lamps an arc 26 feet in length.

Assuming its existence, we need not describe the probable effect of a current of such tension upon the person of any one unfortunate enough to come in contact with the conductor, or the difficulty of insulating the conductor at all; but will simply say that no generator could be constructed around the commutator of which the current generated would not short-circuit. In other words, the current could not be produced exterior to the machine.

With the multiple system (Fig. 68) the conditions are in some respects reversed. The danger of a short-circuit occurring in any branch is avoidable, and the electro-motive force of current being low, there would appear to be no difficulty in insulating the main conductors. The questions arising in the operation of this system relate particularly to the generator.

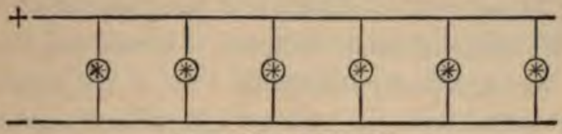

Fig. 68. Multiple Circuit.

Assuming that the generator is so constructed as to give a useful effect in the external circuit of any percentage of the total current, say 75 per cent., and that the resistance of the lamp used is 200 ohms instead of one ohm (for comparison with a low-resistance lamp would obviously be unfair to a system in which lamps of high resistance only are employed), the internal resistance of the generator would be 66.66 ohms, and the total resistance of the circuit 266.66 ohms. Suppose now that we add another lamp to the circuit of the machine; we reduce the external resistance to 100 ohms, because the current has now two paths to traverse, each of 200 ohms resistance. The total resistance of the external circuit becomes 166.66 ohms, and $\frac{66.66}{166.66}$ of the current is wasted in the machine. Let the number of lamps be ten; then we have an external resistance of 20 ohms, and a total resistance of 86.66 ohms. We thus obtain in the external circuit only $\frac{20}{86.66}$ of the current generated, or about 23 per cent. Extending the calculation to one hundred lamps, thus making the external resistance two ohms, we are able to utilize less than 3 per cent. of the current generated. In order to be able to operate one hundred lamps with a utilization of 50 per cent. of the whole current, we must, therefore, reduce the internal resistance of the generator to two ohms; with one thousand lamps, its resistance must be reduced to two-tenths of one ohm; and with ten thousand lamps, to two one-hundredths of an ohm. In order that there may be but little loss in the main conductors leading from the generator, they must be of large size, for the resistance of a copper conductor weighing four pounds per foot is substantially four one-hundredths of an ohm per mile; and as there are two mains, the total resistance of the conductors, costing, as bare copper at 30 cents per pound, $12,672, is eight one-hundredths of an ohm. With such a conductor, the total resistance of the circuit of 1,000 lamps would be .48 of an ohm, divided as follows: generator, .2; mains, .08; lamps, .2. There would thus be wasted in the generator 41⅔ per cent. of the current, and in the mains 16⅔ per cent.; utilized as light, 41⅔ per cent. To bring the utilization up to between 49 and 50 per cent., the mains must weigh 32 pounds per foot, and will therefore cost $101,376. The respective resistances will then be: generator, .2; mains, .01; lamps, .2 of an ohm.

In corresponding ratio the size of one mile mains for 10,000 lamps must be increased, if we desire to approach a realization in light of even 50 per cent. of the current generated, and the internal resistance of the generator must be reduced to two one-hundredths of an ohm. We shall not pause to consider the character of a generator of the required power and of so low an internal resistance, for we have no practical data upon which to base an opinion. The production of a generator of the resistance given, combined with the capacity indicated, is at all events possible. Concerning the requirements of any multiple-circuit generator, however, we are enabled to see that it must be one of multiple induction, the coils of which shall be automatically joined together to form a multiple internal circuit, which shall both increase the quantity of the current generated and reduce the internal resistance of the generator in proportion as the number of lamps in the external circuit is increased and the external resistance reduced. In the mechanical construction of such a generator there is a wide field for study and experiment.

Referring now to the multiple-series system (Fig. 69), it is evident that, in operating 1,000 lamps of 200 ohms resistance each, there may be one hundred branches across from main to main, and in each branch ten lamps, which would make the external resistance of the circuit, not including that of the mains, 20 ohms $\left(\frac{10\times200}{100}=20\right)$. With a resistance in the mains of one ohm, and in the generator of five ohms, making the total resistance twenty-six ohms, there is utilizable as light the ten-thirteenth part of the current generated, or about 77 per cent. Applied to lamps of low resistance, as one ohm each, the arrangement would have to be materially changed ; for, unless changed, the external resistance of the lamp circuit would be but one-tenth of an ohm $\left(\frac{10\times1}{100}=.1\right)$, and the total resistance of the system 6.1 ohms ; whence it follows that we would only be able to utilize in the production of light 1.64 per cent. of the current generated.

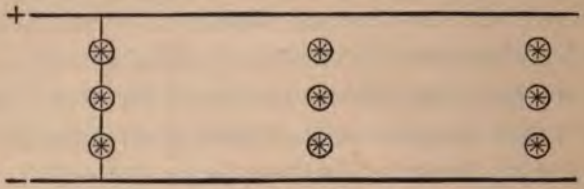

Fig. 69. Multiple-Series Circuit.

Reversing this arrangement and providing 10 branches, each containing 100 lamps, we have a circuit resistance of 10 ohms $\left(\frac{100\times1}{10}=10\right)$; and with a generator resistance of 2.5 ohms, and a resistance in the mains of .25 ohm, making the total resistance 12.75 ohms, we are enabled to utilize as light 78 per cent. of the current generated ; but we must light substantially the entire hundred lamps in each branch at once and extinguish them all at once, or else we must waste the current which would go to the lamps in equivalent artificial resistances when we extinguish a part of the lamps; for, as the current is to be equally divided among all the branches, a branch must in practice either be entirely cut off from, or its entire resistance interposed in, the circuit.

In the fourth or series-multiple system of subdivision (Fig. 70), as in the multiple-series system, the resistance of the external circuit may be anything desired, and there may be operated in the same circuit very many different combinations of lamps. The main conductor, which is single as in the series system, is cut at the points at which light is desired, and from the two disconnected ends a number of small conductors are run each to a lamp or a series of lamps. In the operation of 1,000 lamps by this system there may be, say, one hundred points of divergence, and at each of these points ten lines of wire containing one lamp each. Thus the resistance of the lamp circuit is

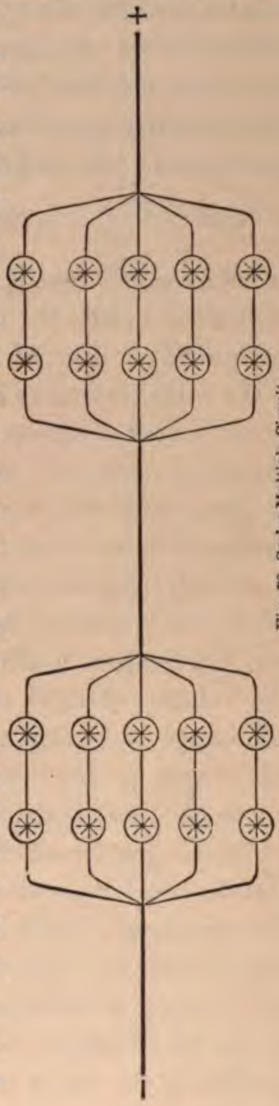

Fig. 70. Series-Multiple Circuit.

made 10 ohms $\left(\frac{100 \times 1}{10} = 10\right)$, and with a generator-resistance of 2.5 ohms, and a resistance in the connecting conductors of .25 ohm, we utilize as light 78 per cent. of the whole current. With 10,000 lamps there may be 500 points of divergence, each containing 20 lamps, by which arrangement the resistance of the lamp circuit becomes 25 ohms $\left(\frac{500 \times 1}{20} = 25\right)$; and with a generator resistance of 5 ohms, and a resistance in the connecting conductors of 1 ohm, the proportion of current available for light is 80 per cent. of the total production.

We might continue these calculations indefinitely, but to no further purpose. The flexibility of the system is obviously such as to permit of any regular combination of lamps whatever, and thus to obtain any external resistance whatever; and it will be found to permit equally well of all irregular combinations, so that in one division, where the volume of light required is great, there may be, say, five lamps in multiple, and in the next division, where the volume of light required is ordinary, there may be ten lamps in multiple, each of the latter receiving but one-fourth as much current as each of the former, because the joint resistance of the ten lamps is .1 ohm, while the joint resistance of the five lamps is .2 ohm; and the ten lamps receive but half as much current as the five lamps, while the number of lamps is doubled. The closing-up, short-circuiting, or reducing the resistance of any division acts simply to reduce the resistance of the whole circuit, in the same manner as removing a portion of the lamps in a simple-series system. The relative advantages of the multiple-series and the series-multiple systems can only be determined by the number of lamps operated from a single source and the practical operation of both systems, although there are considerations of simplicity which would seem to favor the series-multiple arrangement of lamps, whose connection with a line of dwellings is illustrated in Fig. 71.

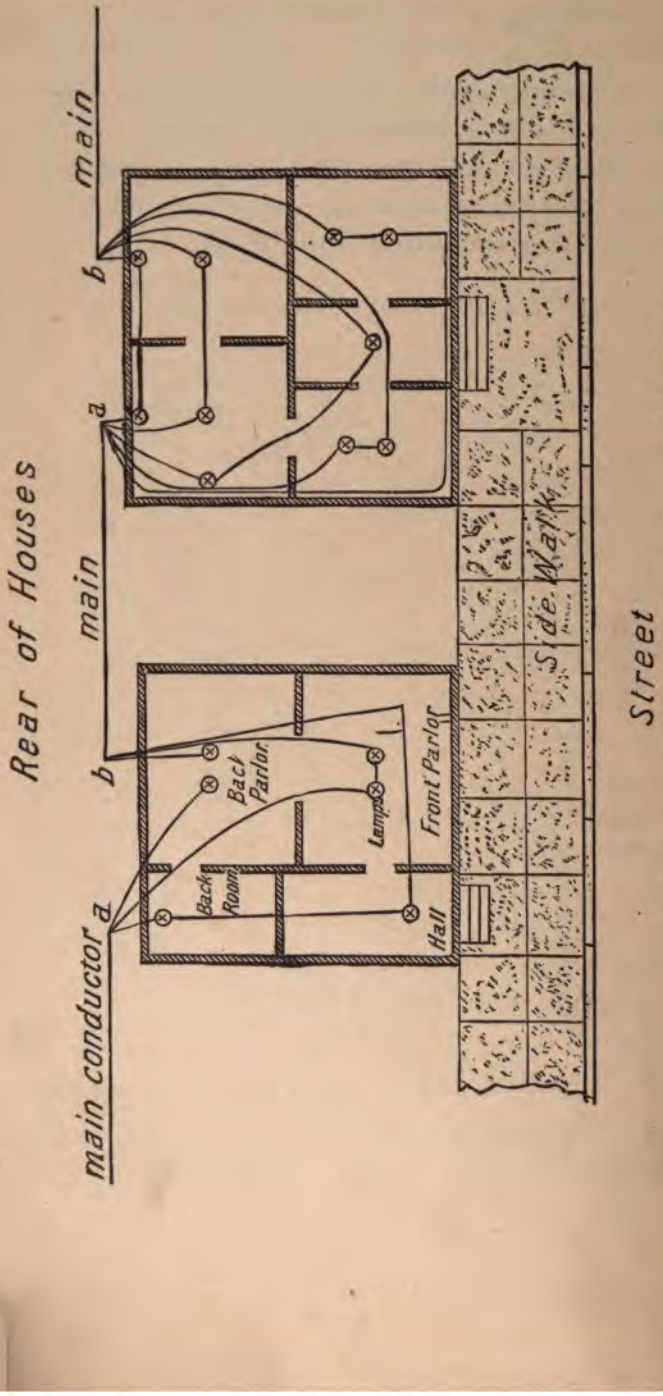

Fig. 71. House-Connections with Main Conductor. *a*, *b*, Points of Divergence.

# CHAPTER X.

## REGULATORS AND SWITCHES.

ALTHOUGH it is matter of common knowledge that a carbon loop or pencil, intensely heated by the passage of the electric current, becomes luminous, it is not generally known what proportion the degree of luminosity bears to the strength of current. The precise relations of the current supplied and the light produced have never been determined; but results which, it is believed, closely approximate the truth were first obtained in August, 1878.

A Sawyer-Man lamp of high resistance (.6 of an ohm) was employed in the tests then made; but it should be borne in mind that, without reference to the length or cross-section of the carbon, so long as the current supplied is in proportion to its length and cross-section, the percentages observed in one lamp are the percentages of all lamps in which wastage of the carbon by chemical action is obviated. Disintegration at the points of contact when these are imperfect, mechanical disengagement of particles of the carbon, and rupture due to imperfections in the constitution of the carbon are occurrences common to all incandescent lamps.

A dynamo-electric machine wound expressly for the purpose, and driven at an unvarying speed, was used;

and as there was abundance of power, and as the speed remained constant under almost any circumstances, it was deemed necessary, in order to obtain a satisfactory result, that the resistance external to the machine should be kept constant. Therefore the internal resistance of the lamp to be experimented upon was measured, and it was found to be as stated. A new form of current-regulator, afterwards known as the Sawyer-Man switch (Fig. 72), was employed in the tests. The poles of the generator had connections at the + and – points, A being a sliding-bar, and the cross-piece B being a spring contact-piece brought to a bearing upon the two rows of studs 1, 2, 3, 4, 5, 6, 7, 8, accordingly as it is moved backward or forward. Whatever position the cross-piece assumes, it will be noted that the resistance of the circuit from the + to the – point is the same. In the position shown, all the current traverses the lamp. With the contact-piece B bearing upon the studs 7, 7, two

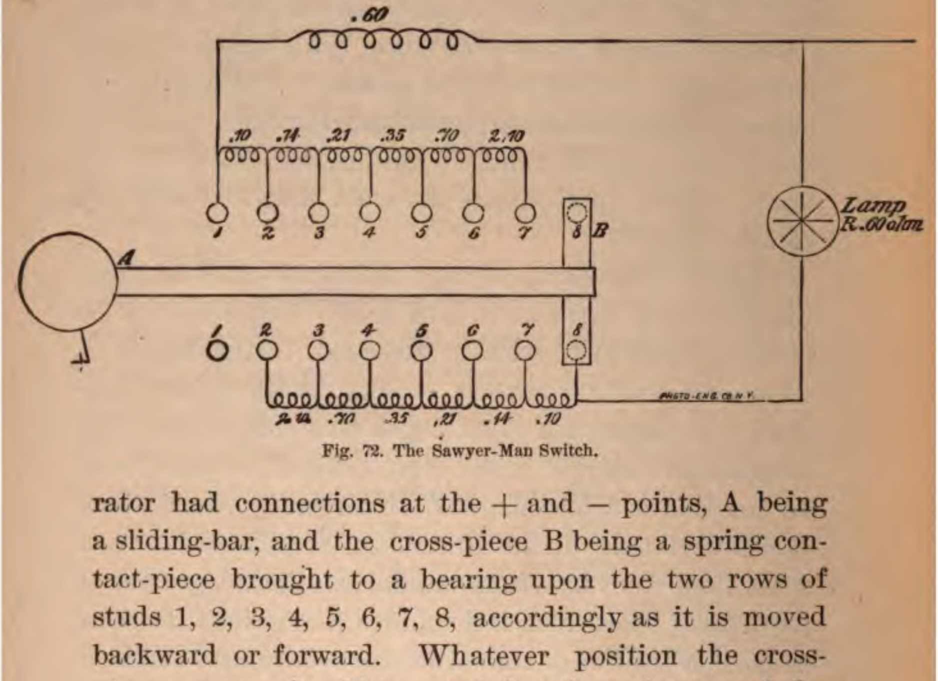

Fig. 72. The Sawyer-Man Switch.

paths for the current are afforded, one by way of a resistance of .10 ohm and the lamp outward, making a total resistance of .70 ohm in that circuit, and the other by way of resistances of 2.10, .70, .35, .21, .14, .10, and .60 ohms outward, the sum total of which series of resistances is 4.2 ohms, thus sending through the lamp six-sevenths of the current, while maintaining the resistance from the + to the – point the same.

It was found that when the volume of current supplied to the lamp was three-sevenths of the whole current, the contact-piece B bearing upon the studs 4, 4, the carbon was brought to a low red-heat. With four-sevenths of the current supplied to the lamp, the carbon gave a light of about one candle; with five-sevenths of the current, the light, measured by a Sugg photometer, was three candles; with six-sevenths of the current, nine candles; with the whole current, twenty-seven candles. When the contact piece B was bearing upon the studs 1, 1, the whole current passed through the artificial resistance of .60 ohm. The gradations of light by this means being too sudden (from less than one candle-light to three candle-light, from three to nine, and from nine to twenty-seven candle-light), the resistances were subsequently changed so as to admit to the lamp first one-half of the current, then five-eighths, three-quarters, seven-eighths, fifteen-sixteenths, thirty-one-thirty-seconds, and finally the whole current. With this arrangement the gradations were gradual and pleasing.

The disparity between the volume of current supplied and the intensity of the light obtained is very clearly indicative of the requirements of an incandescent lamp.

Since five-sevenths of the total current for a single lamp produces but three candle-light, while the whole current produces twenty-seven candle-light, or nine times as much, it follows that in order to secure the maximum economy the carbon must be raised to a high temperature. For if we have a supply of current equal only to the maximum requirements of fifty lamps, from which we may obtain a sum total of 1,350 candles, we cannot divide this current among seventy lamps without sustaining enormous loss, as the sum total of light given by the seventy lamps will be but 210 candles, while the expenditure of power will be the same. There is a compensating influence in the case of lamps in series driven by a dynamo-generator, consisting in the increased percentage of current exterior to the generator when the resistance of the external circuit is increased.

To sustain the high temperatures necessary to the economical operation of an incandescent-lighting system the carbon must be hard, dense, and substantial; and in the absence of these qualities is found the explanation for the inefficiency of fine, filamentary carbons, which can never be safely brought above the temperature of a gas-flame. Carbon incandescence (that of white light), unlike the incandescence of an iron or platinum conductor, is of two grades and various intensities. In the first the carbon is intensely white, and its form optically broadened and lost in a surrounding haze of light. In the second and more intense incandescence its form stands out sharply defined, and it appears no longer opaque but limpid, seemingly translucent, like the body of the sun. It is to this degree of intensity that economical lighting by incandescence is confined.

The Sawyer-Man switch affords a ready means of dividing the current in any desired manner, while maintaining the resistance of a circuit constant. Thus any number of lamps provided with it may be operated by a single generator, and any portion of them may be regulated to any desired degree of intensity without affecting other lamps in circuit. The objection to its use consists in the fact that when a lamp is extinguished the work of the generator is not lessened, but the entire current that served to operate the lamp is wasted in heating an artificial resistance. It was this consideration that led to the designing of the graduating switch (Fig. 73), which is fixed to the wall of a room or in any other convenient place, or attached to the lamp-fixture. In this switch, which is illustrated apart in Fig. 74, there is an insulating disk, upon which are fixed four brass segments of a circle. Over this disk is placed the brass enclosing-cap, through which passes loosely a slotted iron pin carrying

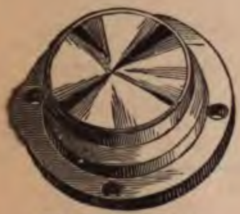
Fig 73. Small Sawyer Switch.

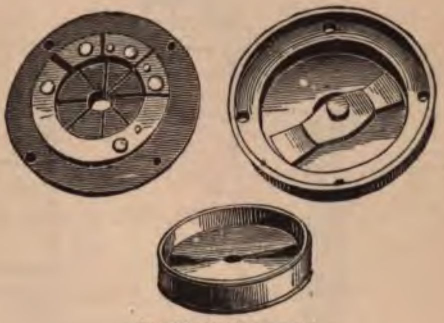
Fig. 74. Switch apart.

a brass contact-bar, which is forced to a bearing upon the brass segments by means of a steel spring coiled in the head of the cap. Upon the end of the iron pin the finger-piece is finally screwed. By turning the finger-piece in one direction or the other the light is turned on or off, or regulated to intermediate points of intensity. In Fig. 75 the switch, as attached to the arm of a chandelier or bracket, is illustrated, the circular case at the end of the arm being shown partly in section. The lamp is fixed to the nipple above the switch-case, and the insulated conducting-wires pass through the hollow arm. The connections of the switch are shown in Fig. 76.

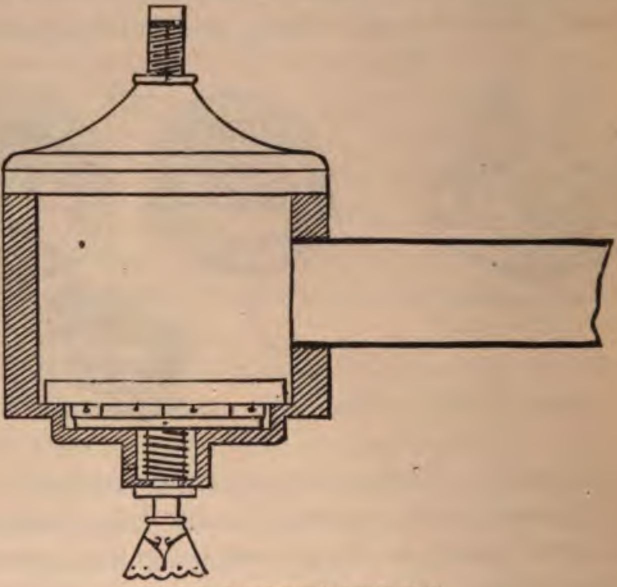

Fig. 75. Switch attached to Bracket.

When both ends of the cross-bar A are bearing upon segment 4, the whole current passes through the lamp. When the cross-bar bears upon segments 3 and 4, the current divides, a part passing through the lamp and part through the artificial resistance of .50 and .25 ohm. When the cross-bar bears upon segments 2 and 4, the current is divided between the lamp and the artificial resistance of .25 ohm. Bearing upon segments 1 and 4, the lamp is short-circuited and practically receives no current. The artificial resistances are preferably made of naked copper wire exposed to the air or embedded in plaster-of-Paris and enclosed in the case (Fig. 75).

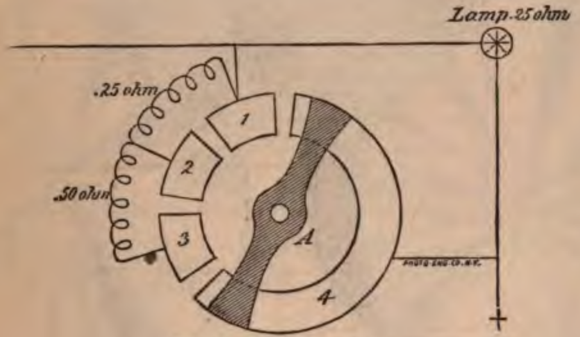

Fig. 76. Switch-Connections.

By means of this switch it is clear that when a lamp is extinguished its resistance is removed from the circuit, and the current is not wasted in heating an artificial resistance. But in order that the changes which take place in its circuit may not add to or lessen the volume of current supplied to other lamps, it is necessary that the changes which occur in its circuit shall in some manner react upon the source of the current; and this brings us to the consideration of regulators operating to supply current in proportion to the requirements of a system.

Before taking up this subject, however, a form of switch designed for use upon a circuit of lamps in series, where interruption of the circuit at any one lamp would, without it, result in extinguishing all the lamps in circuit, will be described.

In Fig. 77 the switch is shown as fixed to the wall of the room, and also with its cover and finger-piece apart. In Fig. 78 the interior mechanism is illustrated. In Fig. 79 we have a diagram of the connections.

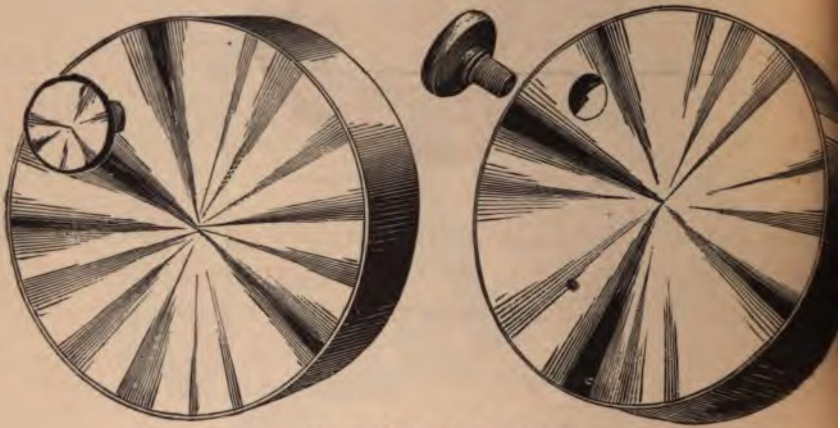

Fig. 77. Electro-Magnetic Switch.

A is the magnet-lever; B and C are other levers; D is a cam operating to raise and lower lever C, which is pressed downward by coiled spring H. Lever B is pressed upward by insulated spring E. F and G are stop-pins, and I is an artificial resistance.

In the position shown lever A is in contact with stop-pin G. Lever B is in contact with stop-pin F, but not with lever A. Lever C is in contact with cam D, but not with lever A. The current, therefore, passes from the + point through the coils of the magnet to the lamp and outward at the — point, the armature-lever being attracted to its contact with stop-pin G and the entire current passing through the lamp. To extinguish the light cam D is moved a little to the right, but not leaving its contact with lever C, when lever C is pressed

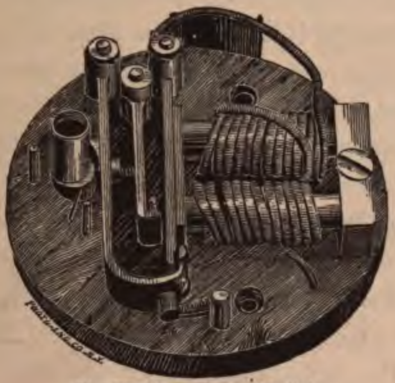
Fig. 78. Mechanism of Switch.

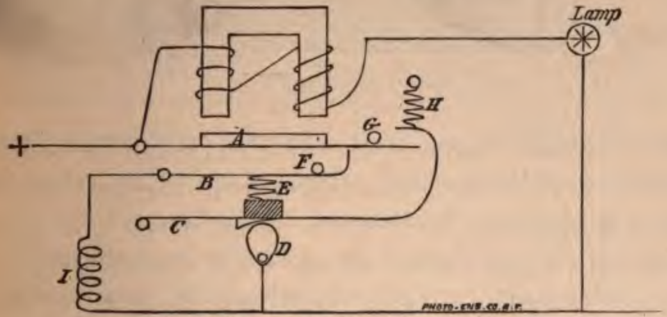

Fig. 79. Electro-Magnetic Switch-Connections.

downward to a contact with lever A. The lamp is thus short-circuited, the current passing from the + point through levers A and C to the cam D and outward at the — point. To give the lamp sufficient current to produce one-half its full light, the cam D is moved further to the right, so as to pass from its contact with lever C. Then lever C, falling further, forces lever A to make connection with lever B, and the current divides, a part flowing from the + point through the coils of the magnet and the lamp outward, and the remainder flowing, by way of levers A and B and resistance I, outward to the — point. With the cam turned to the intermediate point the lamp is extinguished. Turned as far as it will go to the right, one-half of the light is emitted. Turned as far as it will go to the left, the maximum intensity of light is produced. In the event of an interruption of the lamp-circuit the lever A, which, when the circuit is complete, is attracted by the magnet, drops to contact with lever B, and the circuit is re-established by way of resistance I. Lever A can only be drawn towards the magnet when the pressure of spring H is removed by raising lever C from its contact with lever A.

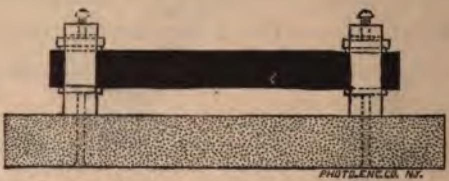

Fig. 80. Carbon Resistance.

A form of artificial resistance useful in electric lighting is illustrated in Fig. 80, in which a rod of carbon is held in brass connecting-clamps upon a soapstone base. A thin piece of platinum, to establish perfect contact, is placed between the end of the carbon and a plate of brass upon which the upper set-screw presses. Copper wire for artificial resistances is preferable to iron wire of equal diameter, owing to the greater surface exposed to radiation and convection of heat by the better conductor; and copper ribbon, for the same reason, is preferable to either.

In the Edison and Maxim systems of lighting the ordinary make-and-break circuit switch is employed. In respect to simplicity it cannot be improved, but it affords no means of graduating the light, which must either be kept at its full power or entirely extinguished. The Edison switch, however, like the switches employed in the Sawyer system, does not interpose current-wasting resistances when no light is required, the supply of electricity being supposed to be regulated at the generator in proportion to the requirements of the circuit.

Many attempts at automatic regulation of the supply of current have been made both in this country and abroad, the nearest approach to its realization by foreign electricians being the device of Dr. Siemens, who in January, 1879, proposed to place a number of carbon disks in an insulating tube, pass the current through them, and by means of a platinum wire, also in the circuit, to vary the conductivity of the carbon pile by varying the pressure of the disks upon each other. For several reasons, unnecessary to state, this arrangement could have no practical application in an electric-lighting system.

The conditions to be met are not so easily met as might appear from a superficial examination. Let us suppose that there are ten lamps, of one ohm resistance each, arranged in multiple circuit, and that each lamp receives one-tenth part of the whole current. Suppose, now, that we add a lamp; then each lamp receives but one-eleventh of the former current. We must, therefore, so increase the supply that each of the eleven lamps shall receive as much current as each of the ten lamps received before. To accomplish this increase, there are two very similar forms of regulators, the first of which was patented by Sawyer & Man, June 25, 1878, and the second of which was recently devised by Mr. Maxim. The latter is illustrated in Fig. 81. Its operation is as follows: In

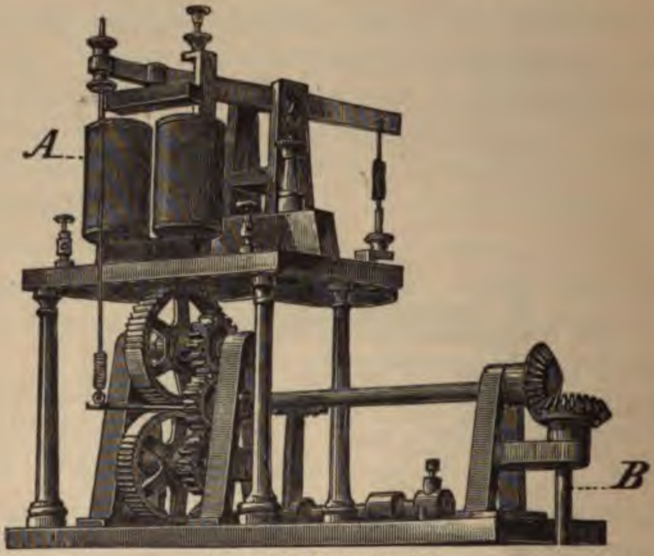

Fig. 81. The Maxim Regulator.

one of the branches across the two main conductors of a multiple-circuit system is placed the electro-magnet A. A proportion of the current, dependent upon the difference in the resistance of the magnet branch and that of all the multiple lamp branches, traverses the magnet-coils; and as this proportion varies according to the number of lamps in circuit, it is obvious that the force with which its armature is attracted varies. When the supply of current is insufficient the armature is released, and by means of a system of gear-wheels, continuously in motion, the shaft B is rotated in one direction, and the commutator-brushes of the generator are thereby so set as to supply a greater volume of current. When, on the other hand, the supply of current becomes too great, by reason of the removal of lamps from the circuit, the armature is attracted, and through the system of gear-wheels mentioned the shaft B is rotated in the opposite direction, and the commutator-brushes are thereby so set as to yield a less volume of current. These are the principles of this regulator, which it is only reasonable to suppose is as yet undeveloped. The considerable changes in current-force necessary to its operation are such as to cause a rhythmical increase and decrease of the intensity of light from the lamps connected with it, owing to the failure of the armature mechanism to act until the strength of the current has too far exceeded or fallen too far below the point at which it must remain in order to produce no appreciable alteration in the intensity of the light. The interposition of a sensitive relay, operating to open and close the circuit of the magnet A, instead of placing the magnet A in the main circuit, would have operated to maintain the intensity of the light constant.*

In the Sawyer system of regulating the supply of current, without regard to the speed of the generator or the electro-motive force of the current (Fig. 82), we have first

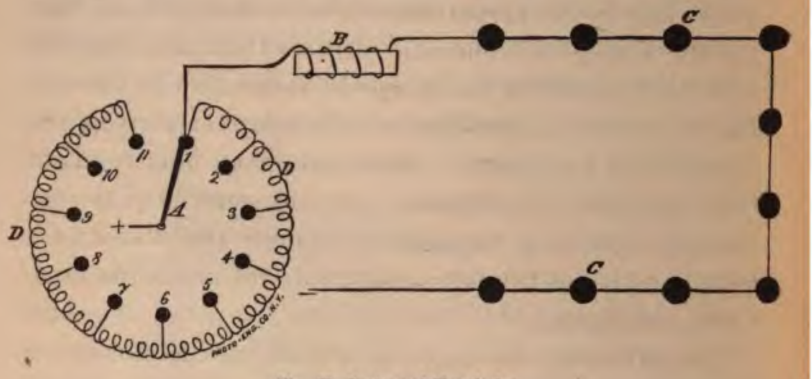

Fig. 82. System of Regulation.

to find the proper relation between the strength of current and the number of lamps to be operated. Let us suppose that there are ten lamps arranged in series, and that the full current is exactly sufficient to operate these lamps at their maximum intensity. At any point in the circuit we place an electro-magnet, B, having the sensitiveness of a telegraphic relay. The relation of this magnet towards the regulating apparatus is actually the same as the relation of the telegraphic relay towards the local telegraphic instrument. The armature-lever of this magnet is set between two contact-points, between which it plays without appreciable motion. Indeed, both points may be in actual contact with the lever, so that the latter shall not move at all; but the local circuit shall be changed by the change in resistance due to the mere difference in pressure of the relay-lever upon the separate contact-points. Thus arranged, variations in the strength of the lighting current, sensible only to a galvanometer, may be made to operate the circuit of a local battery, and thus to energize electro-magnetic regulating mechanism.

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* In Letters-Patent of the United States, No. 223,659, of January 20, 1880, granted to Professors Thomson and Houston, members of the Franklin Institute of Philadelphia, the principles of this regulator are described, with the following claim :

"As a motor for effecting the adjustment of the commutator collecting brushes, an electro-magnet, M, traversed by the current, or a portion of the current, of the machine, whose attraction upon its armature, N, moves said commutator collecting brushes in one direction, motion in the other direction being obtained by the action of a spring."

Let C C be the ten lamps in circuit, and A a rotating contact-lever. D D represent a series of ten artificial resistances, the sum-total of which is 2.5 ohms. The sum-total of the resistance of the ten lamps in circuit is also 2.5 ohms. When all the lamps are in operation, the circuit passes from the + point to the stud No. 1, and thence through relay B and the ten lamps C C to the — point. The resistance of B is for convenience disregarded, as it is but a fraction of the total resistance. Suppose, now, that we extinguish half of the lamps by short-circuiting them. The resistance of the lamp circuit is reduced to 1.25 ohms, and the effect of the current upon B is correspondingly increased. Its lever at once actuates the regulating mechanism, which moves lever A to contact with stud 6, thus bringing the resistance of the circuit to its normal point—viz., 2.5 ohms. The same action ensues whenever a lamp is short-circuited, and the reverse action whenever an additional lamp is thrown into the circuit. In practice the resistances D D are greater in number and each of a less value than described, but the sum-total of all remains the same. The lever of B in practice is in constant vibration between its contact-points, and the lever A is in constant vibration between

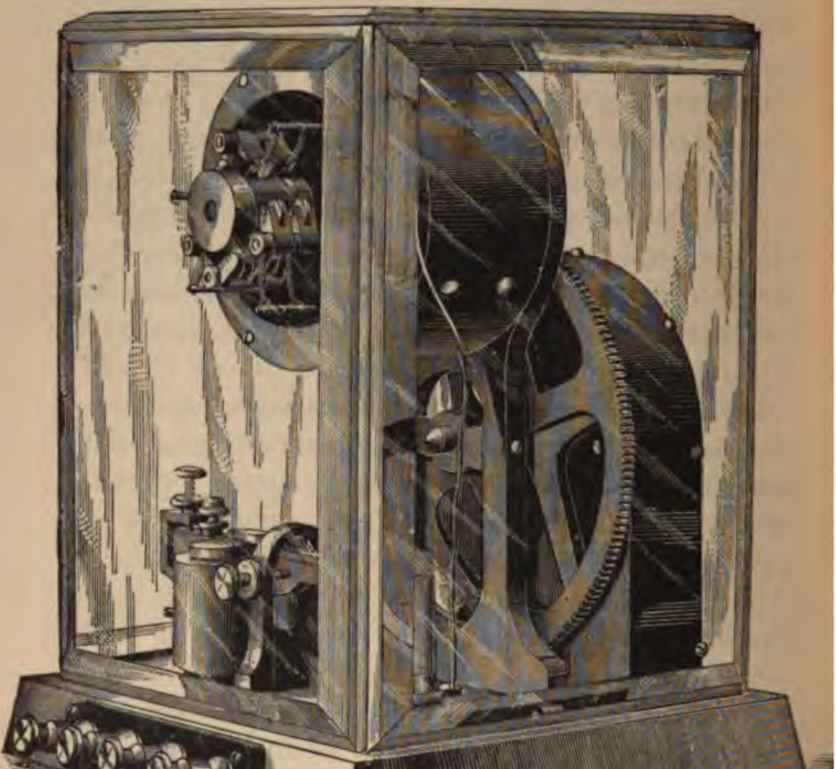
PHOTO ENG. CO. N.Y.

Fig. 83. The Sawyer Electro-Magnetic Regulator.

two contiguous studs or segments of the circle, in addition to its positive movements over a greater or less number of studs.

In the engraving (Fig. 83), from a photograph, is illustrated the Sawyer electro-magnetic regulator. The large gear-wheel, whose shaft carries a rotating contact-arm, corresponding to lever A of Fig. 82, making connection seriatim with a number of insulated segments of a circle enclosed in an oval-top case, is set in motion by a pinion on the shaft of a small reversing electric engine enclosed in the central round metal case. When there is too great a supply of current, the armature-lever of the magnet in the main circuit establishes the local circuit of a commutator which drives the engine in one direction; when there is too little current, the armature-lever establishes the circuit of a second commutator which drives the engine in the opposite direction. In the first instance resistance is introduced in the main circuit. In the second instance resistance is removed from the circuit.

Imperfections due to the oxidization of contact-points in the electric engine, and the occasional failure of the engine to respond to changes in its circuit, led to the abandonment of what was otherwise a successful regulator, and the substitution therefor of hydraulic-cylinder-and-piston mechanism, constituting the regulator shown in Fig. 84, which is also from a photograph.

The internal arrangements of the regulator are shown in Fig. 85, in which J is a hollow metal base containing the various resistances connected with the 18 pieces, F, corresponding to the 10 studs or segments of Fig. 82. B is a cylinder fixed to the base J and open at the top.

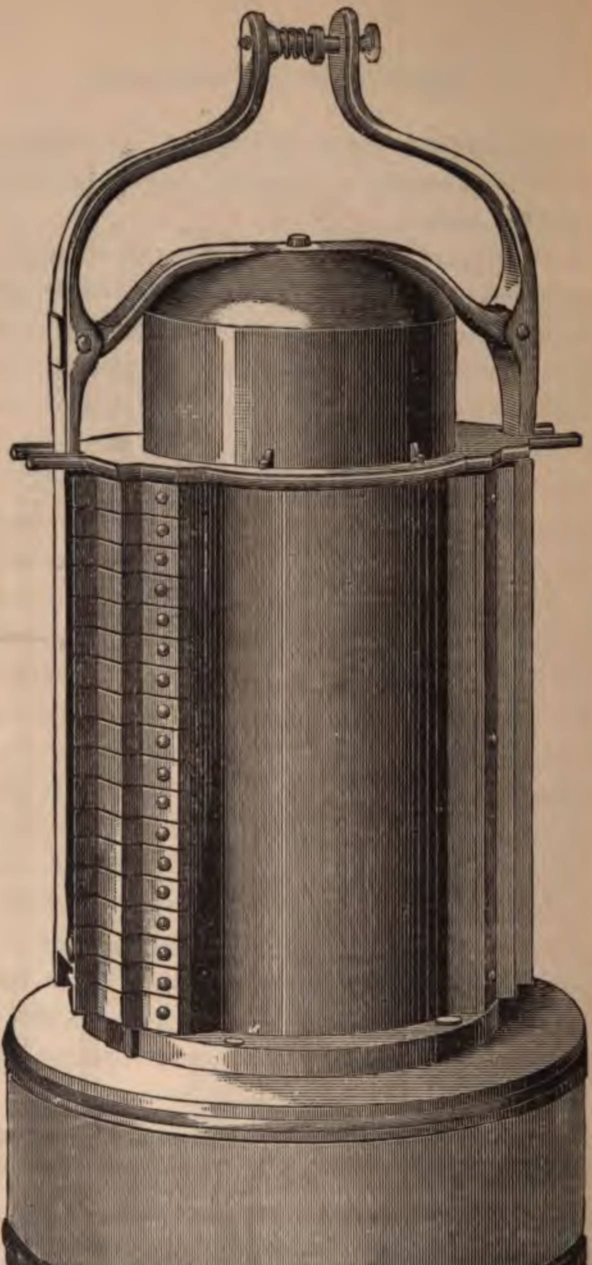
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Fig 84 Hydraulic Regulator.

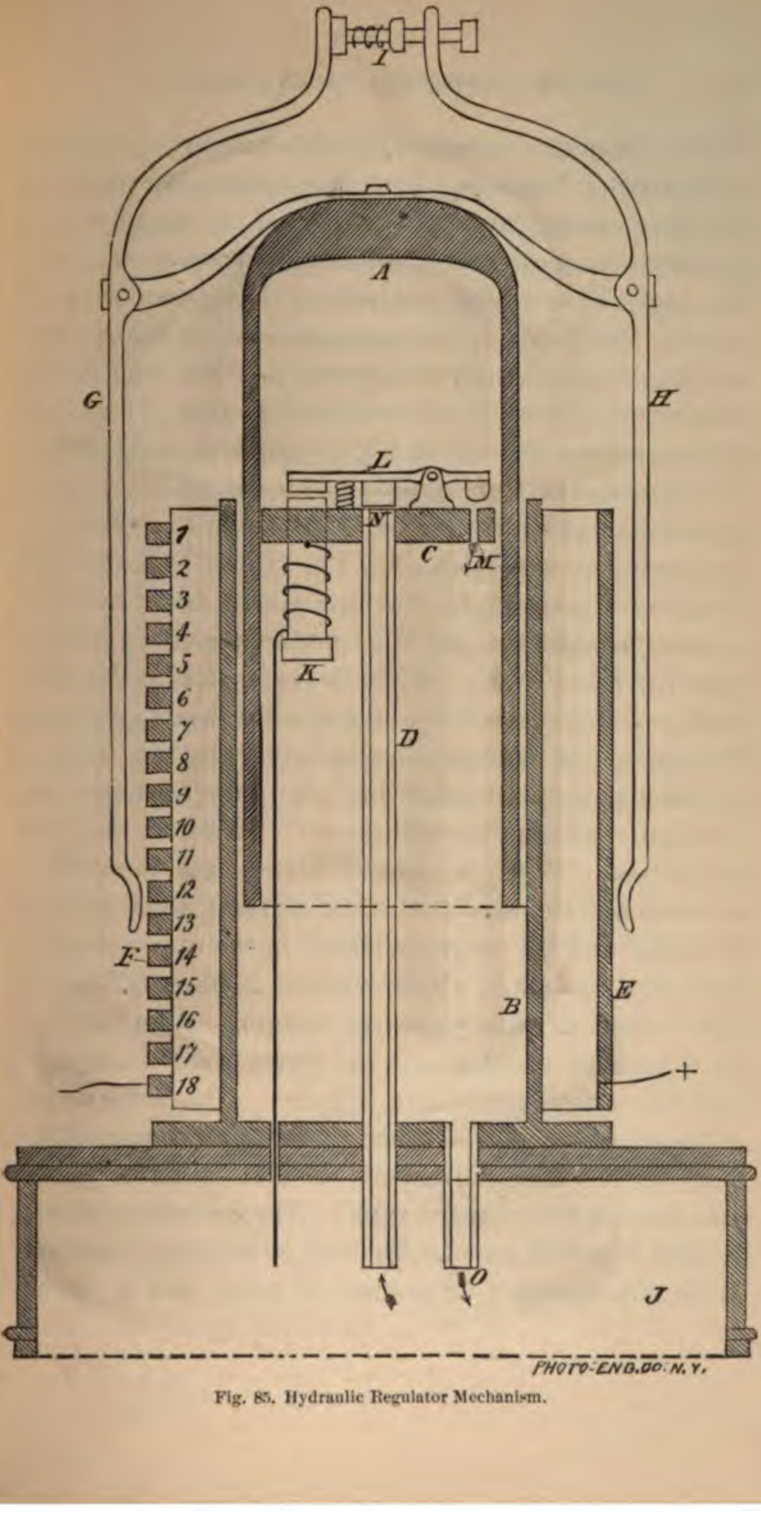

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Fig. 85. Hydraulic Regulator Mechanism.

Closely fitting in cylinder B is the cylinder A, open at the bottom. Supported by a tube passing through the base, and closely fitted in cylinder A, is the piston C. Insulated upon one side of cylinder B is a stationary contact-plate, E, to which one pole of the generator is attached. Insulated upon the opposite side of the cylinder are the 18 grooved central plates F. Running in the grooves of E and F are two contact-arms, G and H, whose pressure upon E and F is regulated by spring I. The current, therefore, passes by way of plate E to arms H and G and a contact-plate F outwardly, as shown in the regulator-connections, Fig. 82. The ends of the cores of an electro-magnet, K, provided with an armature-lever, L, pass through the piston-head, and serve to open and close the valves N M. When the magnet K is not energized, a coiled spring forces the armature away, and valve N is opened to the flow of a stream of water, and valve M is closed against its escape into the lower chamber and outwardly through the exit-tube O. Therefore the cylinder A rises. When the magnet is energized, the valve N is closed and the ingress of water stopped, while valve M is opened and the water contained in the upper chamber is allowed to escape. The cylinder A then falls by its own weight as rapidly as the escaping water permits. By a suitable arrangement the waste water is used to cool the various artificial resistances. The local circuit of the magnet K is established by the back contact of the relay-lever. The movements of the cylinder A are smooth and the changes rapid. The contacts of G and H with F and E are of a firm and substantial character. With a pressure of 10 pounds of water and a piston area of 10 square inches, the cylinder A is raised above its weight with a force of 50 pounds; and as its weight is 50 pounds, it obviously falls with the same force. With a piston area of 80 square inches and 20 pounds pressure of water, a circuit is operated, with singularly rapid changes in the direction of movement of the cylinder, with an upward force in the cylinder of 1,600 pounds. There is apparently no limit to the powerful effects thus producible by minute changes in the strength of current supplied to a system of lamps. By means of these regulators, the changes in the circuit occasioned by the Sawyer switches for graduating the light are instantly balanced; but the fact remains that as much power is expended in driving the generator when there are a few as when there are many lamps in circuit, and in a general distributing system, where economy is the prime consideration, such regulators, however perfect in their operation, can have no practical application.

# CHAPTER XI.

## GENERAL DISTRIBUTION.

THE date of the original conception of the idea of a general distribution system, supplying electricity from a central station to an entire city, and the identity of the person first conceiving this idea, will probably never be satisfactorily determined. The one most deserving of honor in this respect would appear to be Starr. As conceived by Sawyer, thirty years later than the time of Starr, it was patented in the United States August 14, 1877, and it is believed that this was the first systematic reduction of the idea. The illustration (Fig. 86) is a fac-similė of the first sheet of drawings accompanying the specification, printed by the United States Patent Office: R being the central station, in which the generators $a$, $a^1$, $a^2$, $a^3$ are located; $b$, blocks of houses; $c$, points of divergence of mains to lamps, $e$; and $d$, back areas.*

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* The following statement occurs in the specification of these Letters-Patent:

"The object of my invention is to supply the streets, blocks, or buildings of a town or city in a practicable manner with any desired quantity of electricity for the purposes of electric illumination, electro-plating, the running of electro-magnetic engines, etc. I place the generator or generators of electricity in any convenient portion of a locality, whence I carry the necessary conductors over or under ground to the streets, blocks, or buildings in which the current is to be utilized. In place of electric conductors leading from a central station, I may substitute tubes or pipes, through which water

The considerations involved in a general distributing system are of a more complex character than has yet been indicated. In a system in which the lamps are arranged in series the introduction in circuit of additional lamps must operate to increase the electro-motive force of the current supplied to the circuit. On the other hand, in a system in which there is a multiple arrangement of lamps the introduction in circuit of additional lamps must operate to increase the quantity of current supplied to the circuit. In a combination of these two systems there must be a combination of the two operations.

It may be assumed at the outset that in any practical distributing system, the power expended at the generating station in producing current must be proportionate to the current requirements of the system, for obviously we cannot economically expend as much power in operating a few lamps as in operating a large number of lamps. When we reduce the number of lamps it is necessary that we correspondingly reduce the expenditure of power in current production as well as the supply of current to the circuit of the lamps. To a certain extent this must be done automatically; and since power is already provided with the practical adjuncts of con-

or compressed air is carried to a building, there to drive magneto-electric apparatus, etc., for local work. The advantages of my invention are that it enables householders to obtain a supply of electricity for any purpose without the care and inconvenience attending the maintenance of local batteries; that it greatly reduces the cost of electricity to consumers; and that it renders practicable the lighting of buildings by electricity. I do not limit myself in any way as to the number of conduits for any locality, or the purpose for which the electricity is used in combination with my central station."

trol, we must look to the electric regulator for the intermediary means of supplying current in proportion to the demand.

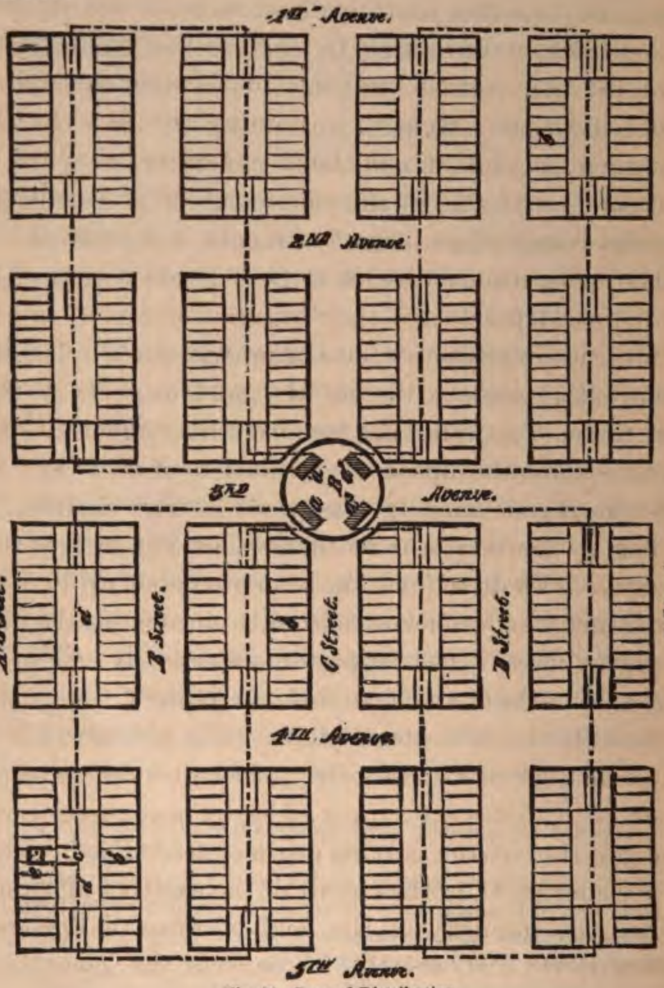
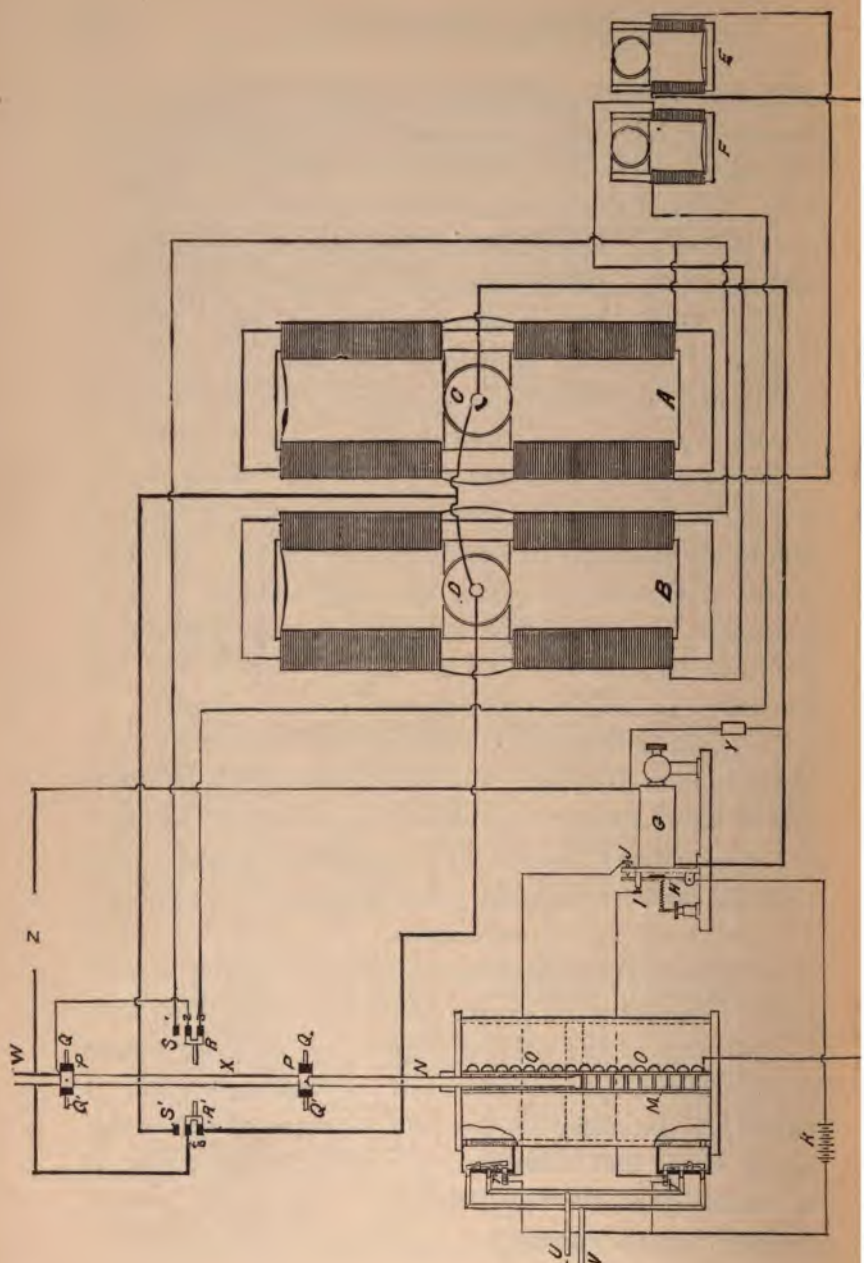


Fig. 86. General Distribution.

To a limited extent, starting from a point of minimum efficiency, we may economically increase the value of the current by increasing the speed of the generator. In this we have the first element of variability in generation. Beyond this point, we may increase the value of the current by increasing the intensity of the magnetic field, in which consists the second element of variability; and as a third element of variability we have the connecting in circuit of additional generators or parts of generators. In Fig. 87 the apparatus of a distributing system, comprising all three elements, is represented.

The generating elements C D E F are constantly in motion, and practically they consume power in proportion to the intensity of their magnetic fields. The machines E F serve to excite the field magnets A B of generators C D, and the intensity of magnetization is governed by the speed of revolution of E F and the amount of resistance, O, interposed in their circuits.

The hydraulic piston mechanism of Fig. 84 acts positively in both directions, the piston moving up or down accordingly as water is admitted to one end or the other of the cylinder. The supply of water is by way of the pipes U, and its waste is through pipes V; magnets T T′ operate the two sets of valves. The piston-rod X has three distinct functions: firstly, through suitable mechanism it regulates the supply of steam in connection with the governor of the driving engine; secondly, by means of resistances, O, in the circuit of the exciting-machine it varies the intensity of the field of force of the generators C D; and, thirdly, it connects the generator D in circuit when the requirements of the circuit become greater than the capacity of generator C, and *vice versa.*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F
E

The contact-arm N serves to vary the magnetic intensity of generators C D by changing its position of connection with the insulated contact-plates M. The pins Q Q, insulated from the piston-rod by collars P, serve to introduce and remove generator D from circuit by changing the position upon blocks S S′ of the sliding connections R R′. When the connections R R′ are in the position shown, the circuit of the distributing mains is from connection R′ to stud $S'_2$ and generator D; thence through generator C, and relay-magnet G, to the system of lamps Z; thence by way of stud $S'_3$ to connector R′. The circuit of the exciting-machines is from connection R to stud $S_3$; thence through exciting-machine F, the coils of magnets B and A and exciting-machine E to the lower regulator-plate $M_{18}$; and thence by way of resistances O to another plate, M, the connecting-arm N, and stud $S_2$ to the connection R. The amount of current flowing through the coils of relay-magnet G is proportioned by an adjustable resistance Y. As lamps are added to the circuit of the main the arm N falls, and by thus removing resistance from the circuit of the exciting-machines the intensity of the field of force of the generators is increased, and more current is supplied to the mains. When lamps are removed from the main by short-circuiting them, there being less resistance in the main and correspondingly less current required, the arm N rises, and the fields of force are weakened; and when the requirements of the circuit are reduced to the capacity of a single generator, the pins Q Q′ throw the connections R R′ upon the pieces S S′, Nos. 1 and 2; generator D and exciting-machine F are removed from the circuit, and power is no longer expended in driving them. The arm N falls to a point upon the plates M at which the intensity of the field of force of generator C is maintained at the proper intensity. The galvanic battery K actuates the valve mechanism of magnets F F′, according as lever H establishes connection with contact-screw I or J.

Such a system of regulation, it will readily be seen, is of indefinite variability, and it is apparent that, disregarding the one element of friction, the power expended in the production of current is almost proportional to the value of the current produced.

The proper construction of the distributing-mains is a matter of great importance, and it is not likely that the best construction will be found without the aid of practical experience. In insulating qualities the degree of perfection of telegraphic conductors need not be expected and should not be required. The mains, especially in cities, should be laid under ground; otherwise the liability of interruption is considerable. With an insulated copper conductor enclosed in an iron tube, the construction is efficient, compact, and simple; and all that remains to be done is to protect the iron from oxidization, and bury the whole well under the surface of the earth. At the central station the insulated conductor is connected to one pole of the generating apparatus, to the other pole of which the enclosing-tube is connected. At the terminus of the main the enclosing-tube and the insulated conductor are connected together. Thus the circuit of the main is from the generating apparatus, by way of the copper conductor, to the distant end of the main, and thence by way of the enclosing-tube back to the generating apparatus. The tube being of iron, its mass per foot of length should be seven times that of the enclosed copper conductor.

In order to divert the current at any point along the route, the main is cut, and its ends enter the sides of a metal box provided with a removable cover. By means of ordinary elbow-joints each end of the copper conductor is connected with an insulated branch conductor at right angles to it, which branches are also enclosed in a tube entering the box (Fig. 88). After the connection is made the box is sealed by filling it with any insulating cement impervious to moisture.

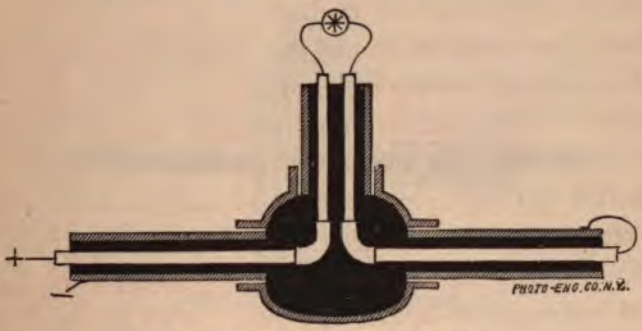

Fig. 88. Underground Main and Branch.

By means of improved machinery the manufacture of insulated conductors, suitable for the purposes of electric lighting, has been made commercially successful. We shall not attempt to decide the respective merits of the methods employed, whose efficiency will be best determined by experience and after long-continued use. One of the recent improvements, devised by Prof. Eaton, consists in passing the copper wire through an insulating material in a viscous state, and thence through a tube around the mouth of which a stream of melted lead is caused to flow (Fig. 89). The insulating material is contained in the cavity A, and the molten lead in the chamber B. The flow of lead through the annular space between the opening in the chamber B and the mouth of the tube C is produced by the pressure of a steel plunger, D, operated by an hydraulic press. The result is a compact and perfect covering of lead around the insulated conductor; and it does not appear that there is any immediate limit to the number of separate insulated strands of copper that may be thus enclosed in a single tube, although, in the manufacture by Prof. Eaton, thus far only seven strands have been insulated.

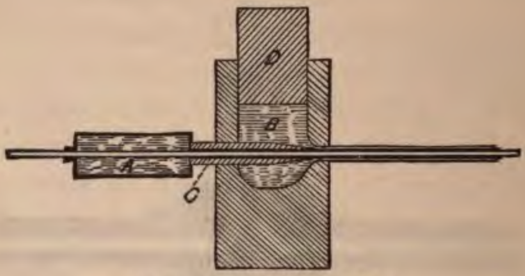

Fig. 89. Apparatus of Prof. Eaton.

The questions which arise regarding the limit of extension of any distributing system cannot yet be answered in a satisfactory manner. To operate from one station ten, fifty, or one hundred thousand lamps may be considered a mere matter of engineering skill, but the limit of the capability for extension of any system must be decided by considerations of cost and practicality. If the lamps to be operated are distributed over a section such as would be included in a circle one mile in diameter, with the generating station located at a central point, there may be said to be no real difficulties in the way; but when we attempt to extend the lighting area the questions of cost then arising are not easily met, and in turning from them we are brought face to face with questions of practicability. The resistance of a circuit external to the lamps and generators is in the mains; and in order that current may be conveyed with a minimum of loss, it is necessary that the resistance of the mains shall be, if not nil, at least inconsequential. If we double the radius of a distributing system, we must double the length of each main; and in order that the resistance of the mains shall not be increased, we must double the mass of metal composing them. Thus we quadruple the cost. It is true, also, that we quadruple the number of mains in order to cover the quadrupled area; but this should not properly be taken into consideration, for it is assumed that only the same number of lamps is operated upon each main in the enlarged as in the original section, and that all the mains radiate in sensibly straight lines from the distributing station. Increasing the radius of lighting area to two miles again quadruples the cost of each main; so that it appears that the cost of mains alone, necessary to conduct the current for a given number of lamps, is sixteen times greater when the distance from the distributing station to the most remote lamp is two miles than when it is but half a mile. For this reason it is extremely improbable that the transmission of electricity to any great distance will ever be attempted.

If it were possible to increase the delivering capacity of a conductor indefinitely by increasing the electro-motive force of the current, it might be practicable to con vey the power of Niagara Falls to the Atlantic seaboard; and if it were possible to devise any arrangement for using the current, it would be possible there to utilize it in the production of light in electric lamps and power in electric engines. We have already had occasion, in describing the connection of electric lamps in series, to speak of the difficulties of insulation. To convey the current of a thousand horse-power a distance of one mile through a copper conductor one-quarter of an inch in diameter would involve a high degree of perfection of insulation in the conductor, and the consequences in loss of life from accidental diverting of the current through the person between the generator and the mile terminus would be such as to prevent its employment in any community. To extend the conductor a distance of five hundred miles, involving an increase in electro-motive force of current of five hundred times, and an increase in the cost of the conductor of five hundred times, would be to magnify the error, the danger, and the impracticability five hundred times. No generator or series of generators which would not short-circuit the current within themselves could ever be devised.

The cost of a quarter-inch copper conductor laid and insulated for ordinary currents is about $1,350 per mile; for a distance of 500 miles its cost would be $660,000, and the cost of maintenance would be per annum—

| | |
|---|---|
| Depreciation at 5 per cent., . . . | $33,000 |
| Interest on investment at 7 per cent., . | 46,200 |
| Total, . . . . . . . | $79,200 |

Leaving out of consideration the cost of maintenance of water-power and the wear and tear of electric generators, and considering only the cost of steam-power in large engines, which may be stated as four-fifths of a cent per hour per horse-power, we are led to the conclusion that the cost of local steam-power is less than would be the cost of these long insulated conductors alone.

A necessary adjunct of any general distributing system is the electric metre, an instrument designed to record or indicate the amount of current consumed. Several methods of measurement have been devised, the most simple of which is the invention of Mr. Edison (Fig. 90).

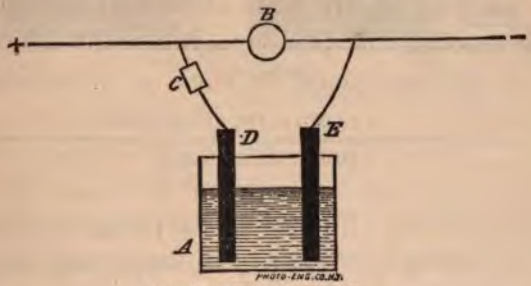

Fig. 90. The Edison Metre.

The Edison metre is based upon the principles of electrolysis. A fractional part of the current supplied to the circuit of a lamp, B, is diverted to a bath, A, of sulphate of copper in solution by way of the electrodes D E. The proportion of current thus diverted is regulated by an artificial resistance, C; and in order to determine the quantity of current consumed in a lamp in any period of time, all that is necessary is to deduct the weight of the cathode before its introduction into the bath from its weight after removal from the bath, and to multiply the remainder by the number of times the resistance of the lamp-circuit is contained in the resistance of the circuit C D E, the electrolytic action of unit current being known. For the R of B being 1 ohm, and the R of C D E being 1,000 ohms, the lamp receives $\frac{1000}{1001}$ part of the current, and the electrolytic bath $\frac{1}{1001}$ part. By arranging in a suitable receptacle a sufficient number of the baths A, each connected with a lamp, the value of the current supplied to any number of lamps may be accurately determined.

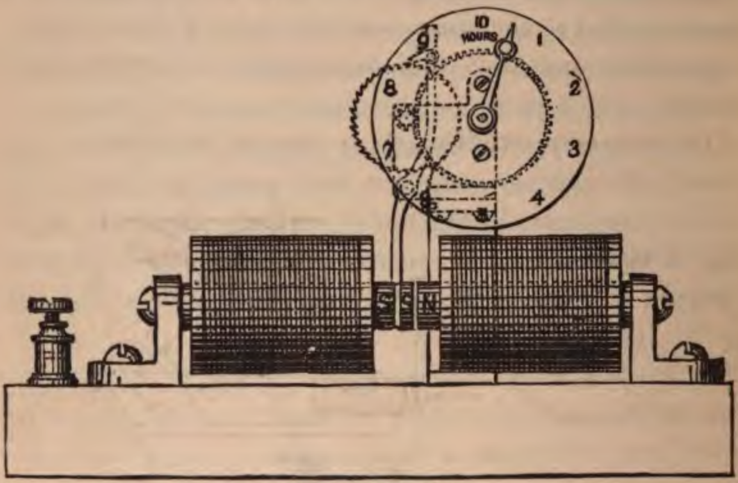

Fig. 91. The Fuller Metre.

The Fuller metre, designed for the measurement of alternating currents, is shown in Fig. 91. The purpose of this metre is to automatically register the number of hours during which a lamp is operated. Two electro-magnets, so wound and connected as to produce the polarities indicated, are placed in the circuit of the lamp. A polarized steel armature playing between the poles of the magnets is connected, by way of the armature-lever, with ratchet-and-pawl mechanism. Changing in polarity of the electro-magnets, produced by the alternating currents supplied to the lamp, serves to keep the armature in vibration, and thus to rotate a train of registering wheels.

The Sawyer metre, Fig. 92, is also a time metre. It

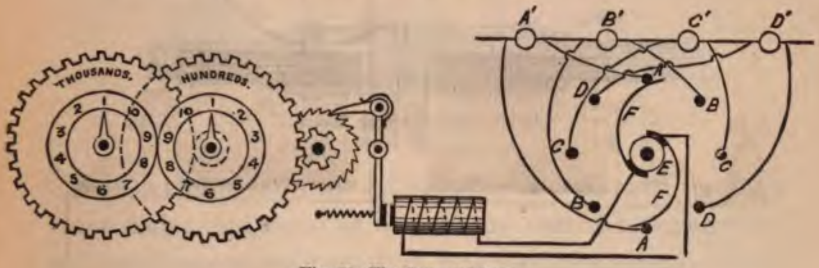

Fig. 92. The Sawyer Metre.

serves to register the time during which a lamp is in use; and since the unit strength of current and the requirements of the lamp are known, it is easy to determine the value of the current used. By means of ratchet-and-pawl mechanism the motion of the armature of an electro-magnet is communicated to a set of dial-hands which are so arranged as to indicate the current consumption or the candle-light resulting from such consumption. A shaft, E, continuously rotated by a bi-weekly or monthly chronometer, carries two insulated springs, F, which are in electrical connection with the coils of the registering magnet, and alternately establish contact with the opposite pairs of pins, A A, B B, C C, D D, thus diverting a small fraction of the current supplied to lamps A′ B′ C′ D′ through the coils of the magnet, each contact of the springs with a pair of pins energizing the magnet and causing the ratchet-wheel to move one tooth. For every lamp added to the circuit there is an additional pair of pins. If only one lamp is in use, the springs F energize the magnet but twice in a revolution of the shaft; if two lamps, four times; if all the lamps are in use, the ratchet-wheel is kept in constant motion; therefore the record of the dial-hands is as exact when one or two are in use as when any other number of lamps is in use, and to determine at any time the consumption of current it is only necessary to note the position of the dial-hands. A more complete metre, to register the variations of current consumed in each lamp, has been devised, and finds special applicability in a series-multiple system; but enough has been written to indicate the methods of measurement that are most likely to come into use.

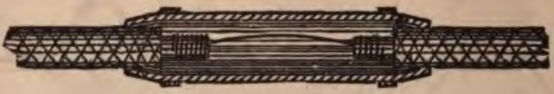

Fig. 93. Edison's Safety Device.

To preserve the continuity of a circuit in case of accident, and to obviate the dangers of short-circuiting, there are several devices of about equally practical application. In the Edison system of distribution obviation of a short-circuit is the one thing necessary, and to this end a section of the circuit of a lamp is composed of a small conductor (Fig. 93), which under ordinary circumstances is unaffected, but which, when there is an abnormal flow of current, is instantly fused.*

To the same end we have the Sawyer-Man Safety-Switch (Fig. 94), operating as follows: The current, in traversing a branch, enters by way of a broad, flat spring and a lever whose movement is stopped by a projection on the end of the armature-lever of an electromagnet included in the circuit. When the flow of current through the branch is normal, the magnetic force developed is insufficient to move the armature, and thus to release the lever; but when, from any cause, there is

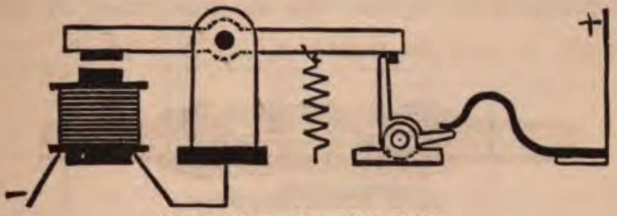

Fig. 94. Sawyer-Man Safety-Switch.

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* In Mr. Edison's description of this appliance he says: "This small conductor has such a degree of conductivity as to readily allow the passage of the amount of current designed for its particular branch, but no more. If, from any cause whatever, an abnormal amount of current, large enough to injure the translation devices or to cause a waste of energy, is diverted through a branch, the small safety-wire becomes heated and melts away, breaking the overloaded branch-circuit. It is desirable, however, that the few drops of hot molten metal resulting therefrom should not be allowed to fall upon carpets or furniture, and also that the small safety-conductor should be relieved of all tensile strain; hence I enclose the safety-wire in a jacket or shell of non-conducting material, which, preferably, is screwed to the ends of the large conductors, uniting them, not electrically, but as to tensile strain."

an excessive flow of current through the branch, the armature is attracted beyond the force of its retracting spring, and the lever through which we obtain the circuit is released, and thus the circuit of the overloaded branch is broken.

In the Brush and the Sawyer systems preservation of the continuity of the circuit, rather than its automatic interruption, is the end sought. In the Brush system the circuit is through the lamp and, by way of a shunt, through the coils of an electro-magnet, whose armature-lever operates to short-circuit the lamp when the circuit of the lamp is interrupted. In the Sawyer system the circuit is first through the coils of an electro-magnet and then through the lamp, and when the circuit is interrupted the armature-lever, being no longer attracted, falls and establishes a short-circuit around the lamp (Fig. 95).

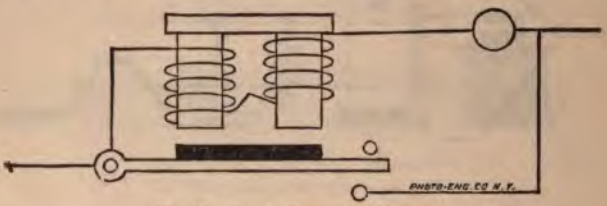

Fig. 95. Circuit-Preserving Magnet.

The Sawyer differential magnet device (Fig. 96) has special application in a series-multiple system of distribution. The circuit from the + point is a divided one, one-half of the current flowing in one direction around the core of magnet A, and the other half flowing in the opposite direction around the core, the divided circuit, including the lamps I, uniting and terminating at the —

point. Thus, when the circuit of each lamp is perfect, the magnetism in magnet A, developed by the current flowing in the circuit of one lamp, is neutralized by the magnetic effects of the current flowing in the circuit of the other lamp, and armature B, attached to lever C (which is pivoted at D and ordinarily retracted by spring E to a contact with stop-pin F), is unaffected. When, however, an interruption of either circuit occurs, the neutralizing magnetic influences of the current upon the magnet A no longer exist, armature B is attracted by the magnet A, and by way of contact face-plates G one-half of the current is diverted to the artificial resistance H. In case of interruption of the circuit of the other lamp, the entire current passes, by way of the core of magnet A and contact-plates G, through the resistance H.

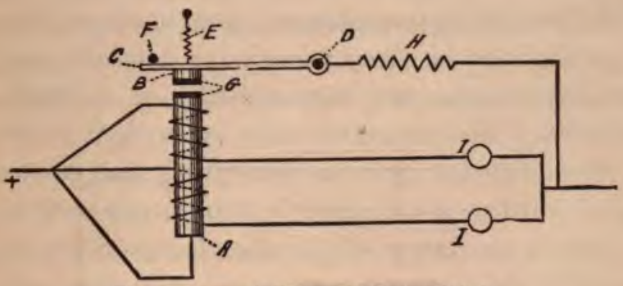

Fig. 96. Automatic Differential Magnet Switch.

## CHAPTER XII.

### COMMERCIAL ASPECTS.

THE light of an incandescent lamp has been shown to be suitable in every respect for domestic use. Its characteristics are the characteristics of daylight. In steadiness it is comparable only to the light of the sun. No other artificial light, not excepting that of the best Argand burner, is as steady. This is not only true of the Sawyer lamp, but of all other lamps in which combustion of the carbon is prevented; and when carbon is raised to the temperature of limpid incandescence, there is no difference between the light evolved and that which, proceeding from the sun, is diffused and softened by the stratum of air it traverses. The heat radiated is much less than that of gas-light of equal power. The noxious vapors proceeding from the combustion of illuminating gas disappear. No chemical action takes place, but hermetically sealed in its crystal chamber, protecting from danger of fire and explosion, a fragment of carbon glitters and glows, rises to the light of a taper, brightens and broadens, and finally illuminates with the effulgence of day. This is what the incandescent light should be, and what it is under proper conditions.

There being no question as to the adaptability of this new illuminant to all the purposes of interior illumination, the other and most important question that arises is one of economy. Is this light, which is better than gas-light, as cheap as, or cheaper than, gas-light?

In the experiments at the South Foreland light-house, conducted by Prof. Tyndall, it was shown that the new Siemens or Häfner-Alteneck machine developed a fraction over 900 candle-light per horse-power expended in driving it, and in one case 1,254 candle-light. We will take the minimum accomplishment as a safe basis for our calculations.

In the best steam-engines the consumption of coal per hour per horse-power is two pounds, costing, at five dollars per ton, one-half cent. One pound of coal yields five cubic feet of gas, and, therefore, the cost of one cubic foot of gas is one-twentieth of one cent. To produce the light of 450 candles by the Häfner-Alteneck machine involves the consumption of one pound of coal, costing one-quarter cent. To produce equivalent light from gas, at a rate of consumption of five cubic feet per 15 candle-light, we must burn 150 cubic feet, and the cost of production, at one-twentieth of a cent per cubic foot, or fifty cents per thousand, is seven and one-half cents. Thus the cost of the electric light is, as to fuel-consumption, but one-thirtieth the cost of gas-light; but there is an advantage, in the respect of coke recovered in the retort, in the case of gas, which may be said to increase the cost of electric light to one-fifteenth the cost of gas-light.

One cubic foot of coal-gas equals 690 heat-units, or 532,680 foot-pounds, and five cubic feet equal 2,663,400 foot-pounds. One horse-power equals 1,980,000 foot-pounds. The five cubic feet of gas, burned in the boiler of a steam-engine recovering ten per cent. of the energy conserved in the gas, will yield in mechanical force $\frac{266,340}{1,980,000}$ horse-power, which would develop in the electric lamp a light of 120 candles. Burned in a gas-burner, it develops but 15 candle-light. Therefore it is cheaper to convert coal into gas, and the gas into steam-power, and the steam-power into electricity, and the electricity into light, than it is to produce light by the direct consumption of gas.

In this it will be noted that the cost of lighting by the voltaic arc is alone considered. We have now to compare with this cost the cost of lighting by incandescence.

The tests of the Konn and Bouliguine lamps, made by M. Fontaine, gave a development of eighty Carcel burners from the current which in an arc lamp produced a light of one hundred burners. Our own experiments, with pencils heated to intense incandescence, have shown a development of but seventy per cent., as against eighty per cent. recovered by M. Fontaine. In order that the lamp may be lasting, however, the development from the same current should not much exceed fifty per cent. of the light of the arc.* Thus, light by incandescence is twice as costly as light by the voltaic arc; hence it may be stated that, taking the estimates above given, the cost of incandescent lighting is about one-seventh the cost of gas-lighting.

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* We have shown in Chapter III. a development by incandescence of 275 candle-light from the current which, in the voltaic arc, yielded a light of 500 candles.

In the estimate of cost of the voltaic-arc light, we have not included the consumption of carbon in the lamp, for the reason that in incandescent lamps the carbon is preserved from consumption; and we have only introduced the subject of voltaic-arc lighting in order to exhibit the verified results obtained by Professor Tyndall and others.

We have not yet considered the cost of plant or the cost of attendance in either the gas system or the electric system of lighting, and we have allowed but 50 cents per thousand cubic feet as the cost of gas, whereas in New York City the average cost of gas-production, all items of expense included, is 70 cents per thousand, and the leakage 8 per cent., while the cost to the consumer is $2 25 per thousand.

The following figures relate to the business of New York gas corporations:

| | |
|---|---|
| Capital invested, . . . . . . | $20,000,000 |
| Gross sales per annum (cubic feet), . . | 2,400,000,000 |
| Cost of gas (70 cents per M.), . . . | $1,680,000 |
| Interest on capital, at 7 per cent., . . | 1,400,000 |
| Taxes, . . . . . . . . | 500,000 |
| Wastage (8 per cent.), . . . . | 134,400 |
| Total, . . . . . . . | $3,714,400 |
| Gross receipts, . . . . . . | 5,400,000 |

Leaving a net profit, over 7 per cent upon the capital invested, of $1,700,000, or a total net profit of 15½ per cent.

The cost of lighting has almost invariably been unfairly stated by the gas interest on the one hand and by the electric-light interest on the other. The statements of the former have been based upon the working of small steam-engines, and the cost of running them, always excessive, and the cost of attendance, also excessive because confined to a limited development of light; whereas with large steam-engines—engines of 500 horse-power and upward—the cost per horse-power is less than one cent per hour. Instead of taking the cost of gas as the basis of calculation, the electric-light interest has considered only the cost to the consumer, which is no more to be considered the cost than the retail price of any production is to be considered the cost of that production. Furthermore, the gas interest has invariably urged the cost of the conducting-wires as an insurmountable obstacle to the general use of the electric light, basing its conclusions upon the sizes of the wire employed in special uses of voltaic-arc lamps where the utmost utilization of the current developed has been attempted.

In no case will the cost of electric mains equal the cost of gas mains. In most cases it will fall below fifty per cent. of the cost of gas mains. In no case will the cost of branch electric conductors equal the cost of branch gas conductors.

In calculating the cost of electric conductors, the following table will be found of use:

### SIZE, WEIGHT, AND RESISTANCE OF COPPER WIRE. SPECIFIC GRAVITY, 8.9.

| Diameter in decimal parts of an inch. | Weight in grains per foot. | Number of feet per pound. | Resistance as pure copper at 60° F. in ohms per 1,000 feet. |
|---|---|---|---|
| 1. | 21,159. | .330828 | .010344 |
| .32573 | 2,245. | 3.11803 | .097501 |
| .134 | 379.93 | 18.425 | .576131 |
| .109 | 251.37 | 27.214 | .870786 |
| .083 | 145.76 | 48.023 | 1.50166 |
| .065 | 89.397 | 78.30 | 2.4484 |
| .049 | 50.803 | 137.79 | 4.3086 |
| .035 | 25.920 | 270.06 | 8.6416 |
| .028 | 16.589 | 421.97 | 13.1951 |
| .025 | 13.224 | 529.38 | 16.552 |

Iron wire, galvanized, in order to have the same conductivity as copper wire, should weigh about six times as much as copper wire per foot. The resistance of iron wire per mile, at 60° Fahr., is, in ohms, 395,000 divided by the square of the diameter of the wire in thousandths of an inch. The weight of iron wire per mile is the square of the diameter of the wire, in thousandths of an inch, divided by 72.15.

The resistance of iron wire increases about .0035 for each degree Fahr. above 60°.

The resistance of copper wire increases about .0021 for each degree Fahr. above 60°.

The question of transmitting electricity (continuous current) to a distance is purely one of resistance of the conductor; and when the resistance of the conductor leading to the lamp-circuit is low enough to permit a satisfactory per cent. realization in the lamp-circuit, that conductor, whether of iron or copper or other metal, and whatever its size or cost, is all that is needed.

We have shown in Chapter IX. that in a series-multiple system of 10,000 lamps, the resistance of the main conductor may be as high as one ohm, and yet permit the utilization as light of eighty per cent. of the current generated. We find by the table of resistances that this conductor, leading a distance of one mile from the supplying station and returning thereto, making its total length two miles, would be substantially $\frac{32573}{100000}$ of an inch in diameter, or less than one-third of an inch. As the resistance of 1,000 feet of this conductor is .097501 ohm, the resistance of two miles of it, or 10,560 feet, would be exactly 1.029 ohms. The cost of this conductor, as copper at thirty cents per pound, would be $1,016 10. The cost of a copper conductor, one mile in length, and a return conductor consisting of an iron tube of equal resistance per foot length, would be about $900. Insulated as a round copper wire, one mile long, in an iron enclosing-tube, the cost would be about $1,000, or twenty cents per foot.*

But here we are brought to the consideration of another question, and one of decided importance—viz., the heating of the conductor by the current traversing it; for it will receive and waste as heat one-twenty-fifth as much current as is used in the lamps, or the heat of 400 lamps, and the surface of the outer tube exposed to earth-conduction is not sufficient to prevent a considerable rise in temperature, with consequent waste of current, equivalent to leakage in a gas system. As much heat would be developed in each section of the conductor thirteen feet long as would be developed in a single lamp, which, although small in itself, owing to the poor heat-conductivity of the earth, would soon appreciably increase the resistance of the conductor. In order to obviate any difficulty from this source, and to realize a greater economy of working, it is well to increase the size of the copper conductor beyond the actual requirements—in this case, say, to a diameter of .65146 inch—and thus to quadruple its conductivity and cost, and to increase the diameter of the enclosing-tube in proportion.

---

* As the prices of metals change this estimate must be changed.

We thus reduce the resistance of the main to .25 ohm, and the waste of current to that of 100 lamps; and not only is the lateral cooling-surface doubled, but the length of main through which the heat of a single lamp is distributed is 52.8 feet, comparable to 105.6 feet of the smaller main. The result is that the very slight heat developed by the current is dissipated, and there is no appreciable increase in the resistance of the main. The cost of such a main, per mile, would be as follows:

| | |
|---|---|
| Copper, at 30 cents per pound, | $2,032 |
| Iron tubing, at 3 cents per pound, | 1,026 |
| Insulation, | 150 |
| Total cost of electric main, per mile, | $3,208 |
| Cost of eight-inch gas main, at 3 cents per pound, | $6,660 |

It will thus be seen how little foundation there is for the absurd estimates from time to time published concerning the cost of electric conductors. By reference to the table of resistances, the reader may accurately determine the cost of the main necessary for any number of lamps, and the percentage of waste in the same. In the case of a system of 10,000 lamps, the waste of current in the mains is almost exactly one per cent., while the leakage of a New York gas system is eight per cent.

By far the greater portion of the plant of a gas system is in poorly-paying, or comparatively poorly-paying, districts. In the lighting of houses where very little gas is used, and in large sections of border territory, there is but little and sometimes no profit. The profits of a gas system are in the lighting of factories and large business houses, stores and hotels, halls and theatres, and the wealthier parts of a city where the most of the gas produced is consumed. The area of New York City is about sixteen square miles, but the most profitable territory would be within the lighting area of eight electric stations, each covering one square mile of territory.

In all places where power already exists, the cost of electric lighting is the cost of the extra coal consumed in the engine, interest upon the investment in lamps and generators, and the cost of occasional renewal of the lamps.

If electric lighting by incandescence is as cheap as, or cheaper than, gas lighting, a comparison of the cost of operating a gas system with the cost of operating an electric lighting system will demonstrate the fact. If electric lighting by incandescence is the more costly, the comparison will demonstrate that fact.

We will take a section of four square miles of New York City, from the better-paying portion of the city.

Thus it will be as favorable for gas lighting in proportion as the better-paying portion of any city is favorable for gas lighting. And it will be favorable for electric lighting as it is favorable for gas lighting.

We will first consider the cost of the gas system.

The investment in the gas plant for sixteen square miles of territory is $20,000,000, as already shown. The investment for four square miles, where there is the largest consumption of gas, is more than one-fourth of this amount, for the cost of the mains is greater, and the cost of machinery and real estate is very much greater, in proportion. We will consider the investment as $6,000,000, and the gas-production as 4,000,000 cubic feet per day. The cost of operating this system per annum is as follows :

| | |
|---|---|
| Interest on investment, at 7 per cent, . . | $420,000 |
| Gas-production, 1,460,000,000 cubic feet per annum, at 70 cents per M., which is inclusive of all connected expenses, . . . | 1,022,000 |
| Wastage of gas, at 8 per cent., . . . | 81,760 |
| Taxes, . . . . . . . . . | 150,000 |
| Depreciation of plant, at 5 per cent., . . | 300,000 |
| Total cost per annum, . . . . | $1,973,760 |
| Gross sales (wastage deducted), 1,343,200,000 cubic feet, at $2 25 per M, . . . . | $3,022,200 |
| Profit over 7 per cent. on capital, . . . | 1,048,440 |

Deducting 8 per cent. leakage from the 4,000,000 cubic feet of gas used per day leaves 3,680,000 cubic feet utilized in light-production, which would allow an average use of 184,000 5-foot burners four hours daily. We are to compare this consumption of gas in gas-lighting with steam-power consumption in electric lighting; and as in the new development of electric lighting we do not consume power except as light is needed, and as more or less light is needed throughout the twenty-four hours of each day, we may employ almost any number of hours as the basis of calculation. Taking the high average of 12 candle-light per burner [see Edgerton's certificate, Chapter VII.], we find that the total light obtainable from 184,000 burners is 2,208,000 candles. These burners are not distributed among 184,000 different apartments, but there are, say, 1,000 apartments, as stores, dining-rooms, etc., averaging 30 burners each, 1,000 averaging 10 burners each, 10,000 averaging 4 burners each, 15,000 of 2 burners each, and 74,000 of 1 burner each, distributing the light among 101,000 apartments. It may be said that at certain hours there are more than 101,000 separate apartments lighted, and at other hours less. This is true, but the electric-lighting system, which consumes power in proportion to the requirements of the system, is capable of expanding and contracting the supply of electricity, just as the gas system is capable of expanding and contracting the supply of gas, and just as economically. It costs less to get 100 horse-power out of an engine capable of developing 200 horse-power than it costs to get 100 horse-power out of a 100 horse-power engine.

In another chapter we have explained the economy of incandescent lamps of large foci as compared with those of small foci. Thus the current generated by the expenditure of from one-half to one horse-power produces in a single lamp a light of 275 candles ; the current generated by one horse-power produces in two lamps in series a light of 120 candles per lamp ; in three lamps, 60 candles per lamp ; in four lamps, 30 candles per lamp ; in five lamps, from 10 to 15 candles per lamp ; the increasing external resistance and the greater percentage of current utilized as light, together with the easier motion of the generator, when the number of lamps is increased, accounting for the proportions given.

In order to supplant the 184,000 5-foot burners of the gas system, we must employ 103,000 electric burners, distributed and requiring power to operate as shown in the following table (page 180), which also shows the distribution, power, and consumption of gas-burners.

It will be noted that these figures are not founded upon a realization of from 10 to 20 lights, of 16 candle-power each, per horse-power of force expended in driving the generator, but upon

2 lamps of 120 candle-power, or
3 lamps of 60 candle-power, or
4 lamps of 30 candle-power, or
5 lamps of 10 to 15 candle-power.

In further division there is great loss. We have never obtained more than 17 lights of 12 candle-power each per three horse-power, and this only in laboratory experiments under favorable conditions ; nor can very much more ever be obtained from magneto or dynamo-electric generators. Further economical division is to be looked

## COMPARATIVE TABLE OF GAS LIGHT AND ELECTRIC LIGHT.

| Number apartments lighted. | Average number of burners in each apartment. | | Total number of burners. | | Illuminating power of each burner in standard candles. | | Total illuminating power of burners in standard candles. | | Total gas consumption per hour in cubic feet. | Total horse-power expended per hour. | Cost of gas at 70 cts. per M. | Cost of steam-power at 1 cent per hour per horse-power. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gas. | Electr. | Gas. | Electric. | Gas. | Electr. | Gas. | Electric. | | | | |
| 1,000 | 30 | 3 | 30,000 | 3,000 | 12 | 120 | 360,000 | 360,000 | 150,000 | 1,500 | $105 | $15 00 |
| 1,000 | 10 | 1 | 10,000 | 1,000 | 12 | 120 | 120,000 | 120,000 | 50,000 | 500 | 35 | 5 00 |
| 10,000 | 4 | 1 | 40,000 | 10,000 | 12 | 60 | 480,000 | 600,000 | 200,000 | 3,333⅓ | 140 | 33 33⅓ |
| 15,000 | 2 | 1 | 30,000 | 15,000 | 12 | 30 | 360,000 | 450,000 | 150,000 | 3,750 | 105 | 37 50 |
| 74,000 | 1 | 1 | 74,000 | 74,000 | 12 | 12½ | 888,000 | 925,000 | 370,000 | 14,800 | 259 | 148 00 |
| 101,000 | .. | .. | 184,000 | 103,000 | .. | .. | 2,208,000 | 2,455,000 | 920,000 | 23,883⅓ | $644 | $238 83⅓ |

for through increased efficiency of steam-engines or other mechanical powers.

In lamps of large foci we find the greatest economy; but it is apparent that, whether we operate lamps of large foci or lamps of so small foci as 10 to 15 candle-power, the cost of the electric light is less than the cost of gas-light, with gas at seventy cents per thousand and steam-power at one cent per hour per horse-power. But we will now consider the total cost of plant and operating and maintaining an electric-lighting system equalling in light-production a gas system using 3,680,000 cubic feet of gas per day.

The following is the investment per station supplying a territory of one square mile:

| | |
|---|---|
| 14 modern steam-engines of 500 horse-power each, | $70,000 |
| Modern improved boilers for same, | 50,000 |
| 20 large dynamo-electric machines, | 80,000 |
| Real estate and appurtenances, | 100,000 |
| 25 miles of mains, at $3,000 per mile, | 75,000 |
| Laying of mains, at $1,500 per mile, | 37,500 |
| Total per station, | $412,500 |
| Four stations, with plant complete, | $1,650,000 |
| Total horse-power, | 28,000 |

The operating expenses of each station per day would be as follows:

| | |
|---|---|
| 1 chief-engineer, | $5 00 |
| 2 assistant engineers, | 6 00 |
| 3 second assistant engineers, at $2 50, | 7 50 |

| | |
|---|---|
| 8 stokers, at $1 50, | $12 00 |
| 1 electrician, | 5 00 |
| 1 assistant, | 2 00 |
| 40 tons coal, at $4 35 in bunkers, | 174 00 |
| Oil, waste, etc., | 10 00 |
| Total per day, | $221 50 |
| Total for four stations, | $886 00 |

These engines would consume two pounds of coal per hour per horse-power, which for four hours' run, and a development of 6,000 horse-power per station, would make the consumption in four hours 24 tons; but, notwithstanding the fact that the consumption is in almost direct proportion to the current requirements, we have thought best, as more or less power will be used during the entire twenty-four hours of the day, to increase the estimate of coal consumption 66⅔ per cent. In practice the consumption would fall considerably below 40 tons, but we have in all cases preferred to make the allowance excessive.

The mains are calculated, not from centrally-located stations, but from stations located upon the outskirts of the territory to be supplied.

We have not yet taken into consideration the cost of renewal of the electric burner, which varies according to the system employed. In the Sawyer lamp, which is renewed without destroying it, the cost per renewal is from eight to ten cents. The average frequency of renewal per lamp (combining in the consideration lamps of all foci) is once in three to four months. There is claimed for the Edison burner a life-time of six months.

In recapitulating the cost of electric lighting per station per year, we obtain the following result:

| | |
|---|---|
| Interest on investment, at 7 per cent., . . | $28,875 00 |
| Depreciation of plant (real estate and appurtenances, and mains), at 5 per cent., . | 8,750 00 |
| Depreciation of engines, boilers, and generators, at 10 per cent., . . . . . | 20,000 00 |
| Taxes, . . . . . . . . . . | 10,312 50 |
| Cost of operating, at $221 50 per day, . . | 80,847 50 |
| 4 renewals of 25,750 lamps, at 10 cents per renewal, . . . . . . . . | 10,300 00 |
| Total per station, . . . . . . | $159,085 00 |
| Total for the four stations, . . . | $636,340 00 |

as against a total cost per annum by the gas system of $1,973,760.

At a rate of $1 12½ per thousand for gas, the gross receipts of electric lighting would be $1,511,100, or a net profit, over and above 7 per cent. upon the capital invested, of $874,760, or a total net profit of 60 per cent. To be as cheap as electric light, gas must be manufactured, all items of cost and management included, at as low a rate as twenty-three cents per thousand cubic feet, without deduction for leakage. We have, however, perhaps overlooked the fact that while from the gas system we obtain a total light of 2,208,000 candles, we obtain from the electric system a total of 2,455,000 candles.

In order that the matter of economy may be made still clearer, let it be assumed that we can accomplish but fifty per cent. of what is shown and what has been done with the electric light—that with an expenditure of one horse-power we can only obtain

1 light of 120 candle-power, or
1½ lights of 60 candle-power, or
2 lights of 30 candle-power, or
2½ lights of 10 to 15 candle-power.

The cost of the engines and boilers would be doubled; that of the generators and remainder of the plant would remain as before. The investment would be increased from $412,500 per station to $532,500 per station, and the cost of operating (in coal-consumption, etc.) would be increased from $221 50 to $415 50 per day. The table of cost would then stand as follows:

| | |
|---|---|
| Interest on investment, at 7 per cent., | $37,275 00 |
| Depreciation of plant (real estate and appurtenances, and mains), at 5 per cent., | 8,750 00 |
| Depreciation of plant (engines, boilers, and generators), at 10 per cent., | 32,000 00 |
| Taxes, | 13,312 50 |
| Cost of operating, at $415 50 per day, | 151,657 50 |
| Renewals of lamps, | 10,300 00 |
| Total per station, | $253,295 00 |
| For the four stations, | 1,013,180 00 |

as against a total cost per annum by the gas system of $1,973,760.

At a rate of $1 12½ per thousand for gas the gross receipts would be $1,511,100, or a net profit, over and above 7 per cent. upon the capital invested, of $497,920, or a total net profit of 30 per cent.

There can be no reasonable doubt that the electric light, which is better than gas light, is cheaper than gas light.

In turning from the contemplation of this subject, it is useful to consider that the advances made in electric lighting within a very few months are of a nature calculated to raise our anticipations to a point beyond the warrant of actual facts. When we recall to mind that from the discovery by Oersted, in 1820, that an electric current would deflect a magnetic needle, and from the later discovery by Faraday of the phenomena of magnetic induction, we have realized the electric telegraph and the electric light of to-day, we may consistently congratulate the age in which we live; but we should not be sanguine that because of all this the millennium is close at hand. The application of electricity to public and private illumination is a realization of the near future no longer to be questioned. It is not probable, however, that electricity will ever entirely supersede gas; indeed, it does not appear that illuminating gas has materially affected the consumption of illuminating oils. There is room, and will doubtless continue to be room, for all methods of artificial lighting, and it is not likely that for many years to come we shall witness anything more than the extensive use of electricity—public buildings and private residences, streets and squares better illuminated than at present, and the new form of light keeping pace with the progress of older and well-tried institutions.

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